

**ENVIRONMENTAL EFFECTS OF ELECTRICAL AND
CONVENTIONAL VEHICLES AND CHARGE STATION LOCATION
PLANNING IN ISTANBUL**

by

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ABSTRACT

Traffic congestion is one of the most important problems in metropolitan regions including Istanbul. Vehicles running with conventional internal combustion engines have low energy efficiency and release harmful substances into the atmosphere. In order to decrease the effects of conventional vehicles, it is beneficial to use environmentally friendlier cars such as phev, bev, hev and ev. Our work includes the analysis of the current situation on the environmental effects and the design of a network for the charging stations in Istanbul. The design of such a system requires extensive data analysis on the origin destination matrices for urban transportation networks as well as the charging requirements of the vehicles.

First part of this thesis focuses on environmental effects of conventional vehicles and how their replacement will affect the environment. In this perspective, we analyse environmental friendlier cars and their infrastructure need. Most important thing for promoting the usage of environmentally friendlier vehicles is opening charging stations in optimal places. We also analyse the effects of passenger vehicles in main roads in aspect of noise and air pollution. Current situation is shown with graphs and tables.

In the second part, we analyse the data for Istanbul and develop a mixed integer linear program (MILP) formulation to design the network of charging stations to satisfy energy requirements. The objective is to minimize the total station opening costs and electricity needs by deciding how many stations to open in each district of Istanbul. We also develop a stochastic programming model to incorporate the effect of a random acceptance rate parameter which denotes the proportion of vehicle owners who plan to use electrical vehicles. We perform a sensitivity analysis on different parameters of the model.

ÖZET

Trafikteki yoğunluk İstanbul gibi birçok metropoliten şehrin ana problemlerinden biridir. Trafikte bulunan araç tipleri ve bu araç yoğunluğun neden olduğu etkiler çevre için olumsuz sonuçlar doğurmaktadır. İçten yanmalı motor ile çalışan ve fosil yakıt kullanan trafikteki araçlar enerji olarak az verimli olmak ile beraber atmosfere zehirli gazlar salmaktadır. Araçların bu etkilerini azaltmak için onları çevre dostu araçlar ile değiştirmek çok faydalı olacaktır. Bu çalışmada şuan araçların trafikte yarattığı durumu incelenecektir ve çevre dostu araçlar ile fosil yakıt kullanan içten yanmalı araçlar etkileri bakımından karşılaştırılacaktır. Şarj istasyonları gibi ulaşım destek sistemleri incelenecektir. Bu tarz sistemlerin dizayn edilmesi şehir ulaşımı ağı için başlangıç-bitiş noktaları matrisi hazırlama ve şarj ihtiyacı tespiti için çok fazla veri analizi gerektirmektedir.

Bu tezde ilk olarak içten yanmalı motora sahip fosil yakıt kullanan araçların ile çevre dostu araçlar ile değiştirilmesinin yaratacağı etkiler incelenecektir. Bu perspektifte, çevre dostu araçlar ve alt yapı gereksinimleri analiz edilecektir. Çevre dostu araç kullanımına insanları teşvik etmek için en önemli şeylerden bir tanesi insanların araçlarıyla rahatça ulaşabilecekleri yerlere şarj istasyonları açmaktır. Kişisel araçların insan yaşamına etkileri ana yollardaki gürültü ve hava kirliliği açısından ele alınacaktır. İstanbul'daki durum grafik ve tablolarda listelenecektir.

Tezin ilerleyen kısımlarında, şarj istasyonlarının açılması gereken yerler kararı için matematiksel model geliştirilecektir. Elektrik ihtiyacı, istasyon maliyeti yada çevre dostu araç sayısı gibi etkiler göz önüne alınarak farklı durumlar için modeller geliştirilecektir. Stokastik modelleme yöntemi ile değişen araç sayısına göre hesaplamalar yapılacaktır. Bütün bu model ve senaryolarda amaç şarj istasyonu minimize etmektir. Bu doğrultuda İstanbul'da şuan ki durum incelenecek ve karışık tamsayılı doğrusal programlama (KTDP) modeli geliştirilerek şarj istasyonu ağı dizayn edilecektir.

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NOMENCLATURE

a	Acceptance rate of environmental friendly vehicles
C_k	Cost of charger k
f_j	Fixed cost opening station in j
r	Range of electric vehicle
d_{ij}	Minimum distances between i and j
I_j	Population of İstanbul
P_j	Population of district j
C_n	Number of vehicles in İstanbul
S_j	Amount of vehicles that can visit node j
T_k	Charging time per vehicle with using mode k
T	Total available charging hours in a charge station
y_k	Maximum amount of vehicle that can be charged in a day with using mode k
$Q_{\max}$	Maximum amount of charger in a station
$Q_{\min}$	Minimum amount of charger in a station
X_j	Binary variable to decide opening station in j
B_{ij}	Binary variable which shows if district j covers i
Q_{jk}	Number of charger k in station j
n_j	Number of station that should be open in district j
h_l	total balancing cost of chargers for the l^{th} scenario
$E_{\text{consumption}}$	Energy consumption of a vehicle (kw/km)
Cost	Electricity cost per kW
E_j	Total energy need for each district
Met_j	Metersquare prices in districts

Chapter 1

INTRODUCTION

Istanbul is the most crowded city in Turkey. It is a city with a population of 13.5 million and the city forms one of the largest urban communities in Europe. It is located in north western Turkey within the Marmara Region on a total area of 5,343 square kilometres [1]. Istanbul is a transcontinental city. It spreads over two continents Asia and Europe with the Bosphorus. The Bosphorus is the one of the world's busiest waterways. Istanbul has strategic position with rail networks to Europe and the Middle East. It is the only sea route between the Black Sea and the Mediterranean [2]. Its location is important for the logistics and transportation industries.

Industrialization and increase in population brings many problems. Istanbul's population has been increasing drastically in the last decades and the current situation shows that the population will continue to increase. One of the consequences of this increase is traffic problem. Traffic is one of the main sources of atmospheric pollution in cities around the world. When the amount of cars increases, pollution and noise increase too. The usage of fuel fossils is the main source of these problems. Communities that use fossil fuels, breathe the poisonous gasses that fossil fuels produce. Gas emissions from fossil fuels should be controlled and decreased. Gas emission can be managed by using environmentally friendly electrical cars. It is predictable that environmental friendly cars will replace conventional cars with the development of technology and depletion of fossil fuels. Many studies have been conducted to investigate gas emissions, electrical cars and charge stations. In the past, some studies have been also conducted in İstanbul.

Increase of electrical vehicles all around the world brings new investment areas such as electrical chargers and charge station. All these things are connected with each other tightly. Changing technology and human aspect of environmental friendly vehicles lead to government and private sector to new investments recently. Many research are made about charging infrastructure needs to optimize planning location of charging stations on different cities all around the world.

In this study, environmental effects of conventional and electrical cars and location decision of charging station model is developed. Different cases are analysed and with changing important parameters to find optimal solution.

Chapter 2 provides necessary background and literature review on environmental effects of conventional cars and environmental friendly cars. Traffic situation of İstanbul is analyzed. Road networks and gas emissions of main arterial roads are reviewed. Also, previous models for location decision of electrical charging stations are reviewed.

Chapter 3 provides information about environmental and economical effects of conventional and environmental cars. Air pollution, noise, global warming effects are analyzed on main arterial roads. İstanbul evaluated as each of these aspects. Current situation and expected situation in future are shown with graphics.

Chapter 4 describes type of cars and chargers. Information about charging modes are provided. Energy consumption of electricity cars and cost of refueling electric vehicle's batteries are mentioned. Existed charging stations and possible charging station candidates in İstanbul are determined. Recommended places in İstanbul for charging stations are listed.

Model details are given in chapter 5. Minimum distance between districts of İstanbul is calculated. With proposed model, amount of charging stations and amount of chargers are determined. Also, electricity need is calculated according to districts to build a proper

electricity infrastructure. Different cases are described and results of them compared to each other. General Algebraic Modeling System (GAMS) is used for finding solutions. The thesis is concluded with a short summary of the performed study and future research work.

Chapter 2

LITERATURE REVIEW

Improved knowledge about the quantity of pollutants become an rising research subject. Many studies have been conducted on environment pollution caused by traffic. In Tekirdağ, Turkey, the exhaust emissions of 1844 vehicles using fossil fuel were investigated randomly at a charging station. The measured carbon monoxide (CO), carbon dioxide (CO₂), hydrocarbon (HC), oxygen (O₂) gas values were discussed in their suitability to the limits determined by Turkish and Europe Standards in 2006 [3]. Coefficients in this study are used in this work.

The air pollution due to exhausted gas from conventional vehicles was studied in tunnels, bridges in İstanbul. The component of hydrocarbons of fuels and exhausted gas from vehicles was also compared by Cumali et al. [4]. This research is also made for Golden Horn Sea to see the effects of pollutants come from vehicles. Many reports about pollution are released for different cities all around the world. Those cities are Dublin, Ireland (Broderick and Marnane, 2002) [5], Taiwan (Yang and Chen, 2004) [6], Chicago (Li et al., 2005) [7], Hong Kong (Xia and Shao, 2005) [8].

Chinese researchers forecasted energy and emission scenarios for the years between 1995 and 2100 using a simulation mode [9]. The aim of the study was to explore possible baseline developments and available options to decrease emissions. In this study, emissions calculated using simulation. Energy requirement, investment potential and cost of user were analysed. It is a beneficial work for our study in İstanbul in terms of findings and methodology.

Research from 2006 shows that transportation vehicle's CO₂ emission is the vehicle rank of 31 and transportation sector is the rank of 17 out of 43 sectors. Extraction of crude petroleum is number one on the list. It is also related to cars and fossil fuels. In this research, an input–output model is used. The model focuses on the relationship between production, fuel use and CO₂ emissions. This study shows that transportation is responsible for %16 of total gas emission. The share of greenhouse gas (GHS) emission of transportation is %13 globally and %21 in European Union [10].

Besides air pollution because of gas emission, noise pollution is another important problem for the traffic. In the literature many studies are conducted the development of a predictive Traffic Noise Model (TNM) [11]. Formulas which depend on traffic density and speed used to predict noise pollution since 1950.

Solution for this emissions and pollutions address research to environmentally friendlier cars. The idea of electric cars first appeared around 1800s. First electric vehicle is designed by Ányos Jedlik and then Robert Anderson created a crude electric-powered carriage. Non-rechargeable electric cells or batteries are used in vehicles by Thomas Davenport and Robert Davidson [13]. Then, Gaston Plante invented a better battery Importance of batteries were understood in these times, therefore studies on it continued. Electric vehicles had many advantages over gasoline cars which are their competitors in the early 1900s. In January, 1990, General Motors release prototype of a high-performance electric vehicle. Since then, many different brands made their electrical cars. With technological development, electrical cars integrated with batteries or gas tanks. They did not have the vibration, smell, and noise if it is compared to internal combustion cars. Changing gears was the most challenging part of driving internal combustion cars, while electric vehicles did not require gear changes [14].

Vehicles work with electricity brings another need. As internal combustion cars need gas stations, electricity cars need electric charge stations. Environmental friendly vehicle

ownership is expanding year by year therefore there is a growing need for widely distributed charging stations. First slow chargers introduced to the market to use in charging stations. With technological developments, charging hours drop to 1 hour with fast chargers. Another alternative for charging station is battery swap stations. In this kind of stations, batteries are switched instead of charged. Both these charging stations have different method to supply energy for the vehicles. As customer aspect, charging preferences might be changed but only unchanging thing is drivers always want to access one of this stations whenever they need. Therefore station location planning is very important and there are many studies on this subject.

Particle swarm optimization is used for planning charging stations in Beijing, China. This work minimizes the comprehensive cost of charging stations and uses traffic flows as a constraint [15]. In addition, the same method is used for battery swap stations in Beijing, China [16].

A Genetic algorithm is used frequently for planning charging stations in the past. He et al, 2012[17] used a Multiple-Population Hybrid Genetic Algorithm to resolve the location problem. This methodology is a combination of Standard genetic algorithm (SGA) and an alternative location and allocation algorithm (ALA). The researchers used a cost minimization model which considers the charging station construction and operation cost and charging cost for electric vehicle charging station.

The Grid Partition model is another method applied for planning electric vehicle charging stations by Ge et al [18]. They use genetic algorithm to choose the best location considering traffic density and charging stations capacity.

The Optimization Cost Model of locating and sizing charging station for electric vehicles built by Feng et al. [19]. In their paper, the number of electric vehicles simulated based on the distribution of residents and they conducted the sites planning with aim of maximizing the profit of charging stations.

The Voronoi diagram is a way of dividing space into a number of regions [20]. Voronoi diagram has recently been used in a number of areas related with the geometric information. This diagram is used for electric vehicle charging station planning by Fen et al. [21]. Their paper presents a novel method for electric vehicle charging station planning based on weighted Voronoi diagram. Traffic load of each intersection node is used as the road network traffic in the model. The number of charging stations is predicted in accordance with the capacity of conventional-standard charging station. Weighted Voronoi diagram is used to partition the road network of planning area. Objective is minimum loss on the way to the charging station while deciding location of charging stations.

Game theory is defined as the study of strategic decision making. Meng et al., 2011 used it for resolving the charging station location problem. Their paper builds a charging station layout optimization based on the Nash equilibrium and combining mixed strategy in game theory [22].

Electric cars and charge stations are affected by several variables. Driving behaviours affect the consumption of energy in batteries. On the other hand, drivers behavioural choices are affected the location of charge stations. Chen et al. [23] creates a behavioural method to resolve charging station locations. Mainly, they analyse the parking space and charging times with the objective of minimizing drivers walking distance from the station to their final destination.

Charge stations can be adapted to parking garages or gas stations [24]. It decreases the initial cost. Moreover, these stations are generally built on most demanding points therefore there might no need to look for a new place to establish a charge stations if electrical infrastructure is enough to satisfy the need.

Different charging patterns affect both electrical infrastructure of city and size of charge station. In multi level charging stations, charger types and charger amount should be

decided carefully in order to stay away from losing customers. Energy demand and charger amount in peak time must be considered while constructing charging stations [25].

Calculating charging demand and building a transportation network model is one of the crucial part of constructing charging stations. Properly designed network is very useful to understand the need. Jia et al. [26] designed a model based on transportation network with using graph theory to analyse sizing and siting need. Objective of this model is minimizing the cost of charging stations and consumers.

After constructing charging stations, it is important to use them optimally. All roads should be analysed as node points or arcs to see how optimal they can be used. Worley et al. [27] created set of routes with using nodes and planned charging station locations, where vehicles come from a single node. In this model, charging stations must satisfy all demand and electrical vehicles cannot travel a distance more than their range without visiting a charging station on the route. Objective of this model is to minimize the sum of the travel costs, recharging costs and costs of locating charging stations.

Chen et al. [28] use stochastic model to find charging demand. Particle swarm optimization (PSO) is used with stochastic parameters. Daily arrival and departure times consist of stochastic input data. Charging places are resident's parking lot not public charging stations. Their model is developed to reduce the power fluctuation level because of electrical vehicle charging.

There are many factors to decide location of charging places. Lam et al. [29] mainly concentrate on human factors rather than technological factors. Electrical vehicle drivers should always be able to access a charging station without any concern of fuel depletion. It is a key for location modelling of charging stations in this study. They built four different models with using Iterative Mixed-Integer Linear Program, greedy approach, Effective Mixed-Integer Linear Program and Chemical Reaction Optimization. Results are compared

according to solution quality, algorithmic efficiency, problem size, nature of the algorithm and prerequisites.

Battery swap stations are alternative to charging stations. Drivers change their cars batteries instead of waiting long hours for recharging. Ip et al. [30] focuses on planning BEV charging locations in urbanized areas with high traffic density and problematic power grids. Clusters are created and Euclidean Distance formula is used to find distances between two places. Road traffic density and their predicted demands are used for deciding capacity. Linear programming model is used for building stations to the clusters.

Chapter 3

ENVIRONMENTAL AND ECONOMICAL EFFECTS OF CARS

3.1.Environmental Effects

3.1.1. Air Pollution

Air pollution sources can be classified as: residential heating, motor vehicles, industrial plants etc. Emission which comes from vehicles is one of the biggest sources of air pollution.

All modes of transportation are major contributors to gas emissions since they use fossil fuels. While a vehicle's engine is running, several different types of gasses and particles are emitted. Gas emissions from cars, which are due to the combustion of fossil fuels, are the largest source of greenhouse gases that go into the atmosphere. These harmful gases are carbon monoxide (CO), carbon dioxide (CO₂), nitrous oxide (N₂O) and particular matter. It poisons humans breathing air. Air pollution is responsible for many cases of respiratory illness every year. Gas emission is an immediate health concern as people breathe the polluted air directly into their lungs. Car exhaust also causes bronchitis, asthma and other health hazards. Vehicle pollution damages neuron cells that are related to learning and memory and causes Alzheimer illness. Benzene is one of the pollutants released by conventional cars. This pollutant has been linked to decreasing immunity, leukaemia and cancer [31]. It is clear that any reduction in fossil fuel usage will certainly decrease gas emissions.

Istanbul particularly suffers extreme air pollution mostly due to its very high population. Besides it is in a strategic position for transportation and logistics sector. Majority of personal cars and all of the public transportation modes use fossil fuels and unfortunately Istanbul's high population just magnifies the effect of emission on air pollution. An environmentally friendly solution is the encouragement of electrical car usage by setting up an efficient charging station network in Istanbul.

3.1.2. Noise Pollution

Noise levels in cities are increasing drastically due to heavier traffic and more powerful engines. Vehicle noise has become the primary source of noise pollution. Noise pollution may cause a number of disturbing effects on human health. It is one of the reasons for mental stress, hearing defect and lack of concentration. Noise can cause or bring about disturbance to work, relaxation and sleep. Furthermore, it disturbs the natural habitat and animals [32]. There is a high noise pollution in Istanbul as it is a huge metropolitan and approximately there are two million vehicles. Noise impacts vary by the type of vehicles.

Noise level should be less than 74 dB (decibel) in order to protect natural life. Typical noise levels for passenger vehicles changes from 72 to 74 dB [32]. Decreasing the effect of noise that come from vehicles is a costly operation. However, there are some methods in order to decrease noise levels. Noise barriers between the road and affected receivers would reduce noise levels by physically blocking the transmission of noise from vehicles. Example of these noise barriers can be seen on highways all around Turkey. Noise walls should be high enough to break the line-of-sight between the noise source and the receiver. They must also be long enough to prevent significant flanking of noise around the ends of the wall. When we analyze the noises come from cars, their approximate noise level dB (A) is 70, 26. Lower limit is 65 and upper limit is 75 for the vehicles [33].

There are some basic statistics models to calculate noise level. The development of these models to measure traffic noise started more than 50 years ago and they are known to give pretty accurate results. One of the first models, for instance, which is developed in 1952 is [34]

$$L_{50} = 68 + 8.5\text{Log}(Q) - 20\log(d) \quad (3.1)$$

where Q is traffic volume in vehicles per hour and d is the distance from observation point to the traffic. It is a general formula without considering type of vehicle. L_{50} is the noise level exceeded for 50% of the measurement duration [35]. It is the middle point and has been incorporated in some American Community Noise Assessments. [36]

Johnson et al. [37] present a model that considers the mean speed of vehicles in mph, v . The formula is

$$L_{50} = 3.5 + 10\text{Log}\left[\frac{Qv^3}{d}\right] \quad (3.2)$$

Common point of both of these models is that they are for light cars such as passenger cars. Other methods in literature also consider heavy vehicles.

	Road Number	Average Speed	Distance(d) (feet)	Amount of car/hour	Result from Formula 3.1	Result from Formula 3.2
Istanbul	016-02	95	10	691	72.13578599	81.2267505
Istanbul	020-05	76	10	39	61.51219842	65.82111179
Istanbul	020-05		10	122	65.7378389	
Istanbul	020-06		10	23	59.5946948	
Istanbul	020-06	94	10	92	64.68550296	72.32383909
Istanbul	020-06		10	1,343	74.58990571	
Istanbul	020-07		10	167	66.89216886	
Istanbul	020-07	97	10	527	71.13363863	80.31919747
Istanbul	020-07		10	261	68.54026548	
Istanbul	020-07		10	291	68.94678851	
Istanbul	020-08		10	104	65.14034381	
Istanbul	020-08	62	10	30	60.60644876	62.10286687
Istanbul	100-04		10	469	70.70300089	
Istanbul	100-04		10	730	72.33740141	
Istanbul	100-04	98	10	1,034	73.62342458	83.38198766
Istanbul	100-04		10	843	72.86898697	
Istanbul	100-04		10	1,165	74.06522239	
Istanbul	110-05	107	10	513	71.032698	81.4788051
Istanbul	567-02	110	10	316	69.24149459	79.73177419
Istanbul	567-02		10	73	63.82346561	
Istanbul	569-01		10	241	68.25033462	
Istanbul	569-01	89	10	504	70.97004914	79.00528742
Istanbul	569-01		10	404	70.15348008	
Istanbul	34-01	95	10	691	72.13578599	81.2267505
Istanbul	34-06	60	10	123	65.77168889	67.75240679
Istanbul	34-07	57	10	6	54.81387494	54.19256913
Istanbul	34-08	62	10	181	67.18005625	69.83652275
Istanbul	34-25	64	10	169	66.92701192	69.95247206
Istanbul	34-81	72	10	111	65.38385936	69.67157414
Istanbul	34-81	63	10	18	58.63547648	59.99254176

Table 3.1: Calculated noise levels dB (A) of some roads in İstanbul

3.1.3. Water Pollution

Some of the air pollutants released from vehicles can be deposited on soil and waters. These pollutants can affect the immune, respiratory and neurological systems of human and animals [38]. Nitrogen oxides and sulphur oxides contribute to acid rain creation. Acid rains change the pH value of waters and soils and harm beneficial organisms that rely on these resources. In addition, when it rains, air pollution from vehicles mixes with rain and falls to rivers and seas which increase the water pollution [38]. Ultimately, drinking water is affected by all those harmful particles. Oil as a fossil fuel is a corruptive water pollutant. Small amount of oil can severely contaminate water sources. Fish and aquatic life is affected adversely.

3.1.4. Global Warming Effects

Changes in climate have been seen for years all over the earth. Greenhouse gases directly affect the environment, weather and health. Future temperature changes depend on levels of atmospheric greenhouse gases. In İstanbul, in particular, climate change affects can be seen obviously. Temperature in the summer season has an increasing trend compared to the past ten years. Global warming causes water shortage in water dams and consequently a lack of fresh water. In addition, the fertility of agriculture and variety of agricultural products have been decreasing. Increases in temperature and changes in seasons are the most obvious signs of global warming in İstanbul. The most important contributor to these effects is the usage of vehicles with fossil fuel. Vehicle emissions contain few chlorine or bromine heavy substances and this cause ozone depletion. To decrease these effects, replacing conventional cars with environmentally friendly cars is important [39].

3.1.5. Effects of Vehicles on Environment in General

Vehicles have important effects on the environment in different ways. Greenhouse gas effect from the fuel combustion in transportation vehicles causes global warming which is destructive for open land and wildlife habitat, species preservation, invasion of exotic species and support for ecological systems. Cars pollute the air, water and land. Noise is another effect which causes a distribution. Effects on air can be altered by changing the type of fuel. Currently, it is the most significant problem for vehicles and it can be solved by using environmental friendly cars and fuels.

3.2. Economical Effects

3.2.1. Dependency on Petrol

Petroleum is the most fundamental energy input for economic development and energy sector and requirement of petroleum increases day by day both in the world and Turkey. Turkey has limited petrol resources and it decreases day by day. Especially, fossil fuels and its derivatives are limited. It is clear that dependency on other countries to import petrol will increase in the future. Turkey's economy is drastically affected as it already depends on other countries with crude oil resources. Prices of petrol will increase too if Turkey continue to depend on external suppliers. Petrol import is an important part (between %4 - %10, but generally %6) of total import amount of Turkey [40]. Although petrol is used for producing natural gas etc., it is mostly used for vehicles. Therefore, changing the type of energy will definitely be beneficial economically.

At the end of 2009, petrol reserves was 44.3 million tons. Production in 2008 was 2.2 million tons and consumption was 27.8 million tons. Production amount in 2009 was 2.4

million tons [41]. As it can be seen here, difference between production and consumption is too high. Turkey's petrol reserves cannot supply the needed petrol and it makes Turkey dependent on other countries. Due to the concerns about oil supplies and oil prices, environmentally friendlier cars offer more stability than conventional cars.

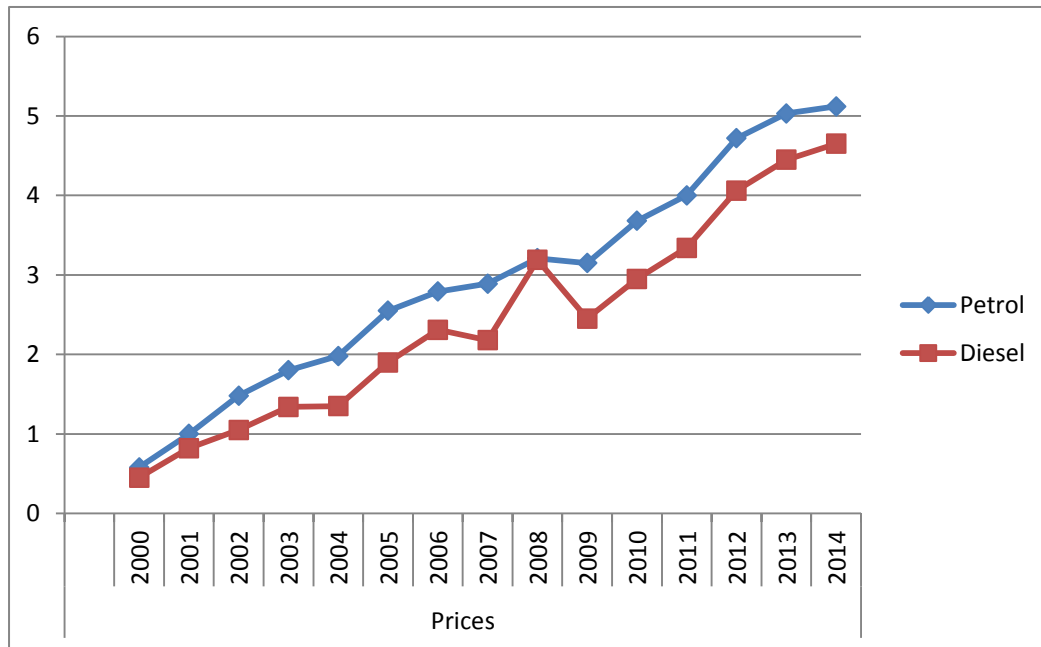


Figure 3.1: Prices of Diesel and Gas According To The Years

Petrol and diesel prices [42] increase in different rates in each year. According to the increase in the past, it is expected that future prices will be as represented in Figure 3.2

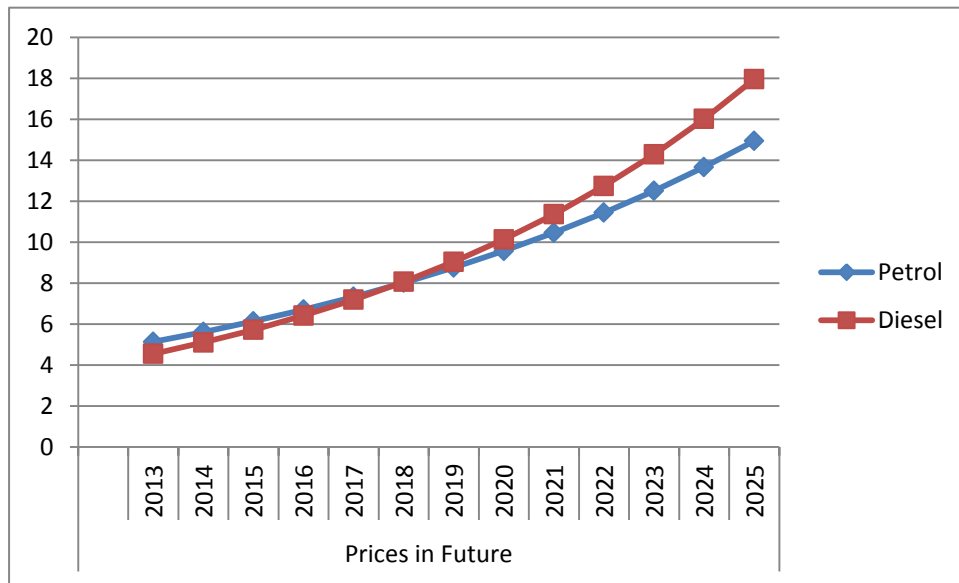


Figure 3.2: Estimated Prices of Diesel and Gas According To the Years

3.2.2. Electricity

Since electricity is invented, it becomes vital in almost all aspects of society. Electricity has a wide range of usage area. It is an important part of transportation for many years. Electric motors in vehicles provide a clean and efficient means of motive power. Transport trains, buses, trams and cars use electricity. Vehicles use it as the motive power, meaning that electricity drives the wheels to make the vehicle move. Even gas and diesel powered vehicles use electricity to start the engines, control the engine and power the ancillary devices [43]. In the future, petrol seems to be replaced by electricity in transportation area. In Turkey, prices of electricity according to the years can be seen in table 3.2 [44].

Years	17:00-22:00 Krş/kwh	22.00-06:00 Krş/kwh	06:00-17:00 Krş/kwh
2009	15.30326451	26.38332014	7.3350
2010	15.208835	26.22052	7.2897
2011	15.70808359	28.02857024	6.8236
2012	18.044875	32.28527146	7.7752
2013	18.0449	32.2853	7.7753
2014	18.0549	32.2953	7.7833

Table 3.2: Electric prices according to years and hours in a day

According to the last released report from EPDK [45]:

%48,6 of electricity produced by natural gas

%28,36 of electricity produced by coal

%18, 6 of electricity produced by hydropower

%3,46 of electricity produced by liquid fuels

%1,16 of electricity produced by renewable electricity sources

3.3. Istanbul with Numbers

Population of İstanbul increases continuously. As a result of this, number of cars increase too. According to research by Turkish Statistical Institute (TUIK), population will reach to approximately 16 million. The population increases %2 approximately every year in Istanbul.

Districts in İstanbul	Population	Annual growth rate of population (%)
Adalar	16166	105,2
Arnavutköy	215531	49,9
Ataşehir	405974	25,5
Avcılar	407240	29,8
Bağcılar	752250	4,3
Bahçelievler	602931	4,6
Bakırköy	220974	-1,6
Başakşehir	333047	52,0
Bayrampaşa	269677	-0,4
Beşiktaş	186570	2,7
Beykoz	248056	6,9
Beylikdüzü	244760	66,1
Beyoğlu	245219	-3,8
Büyükdere	211000	55,2
Çatalca	65811	-4,9
Çekmeköy	207476	71,4
Esenler	461621	6,4
Esenyurt	624733	121,3
Eyüp	361531	14,0
Fatih	425875	-7,0
Gaziosmanpaşa	495006	13,7
Güngören	306854	-2,3
Kadıköy	506293	-28,6
Kağıthane	428755	17,4
Kartal	447110	8,6
Küçükçekmece	740090	24,9
Maltepe	471059	21,7
Pendik	646375	32,4
Sarıyer	304406	87,2
Sancaktepe	335598	-2,0
Silivri	155923	37,5
Sultanbeyli	309347	22,8

Sultangazi	505190	26,0
Şile	31718	48,4
Şişli	274420	9,2
Tuzla	208807	54,9
Ümraniye	660125	22,8
Üsküdar	534636	-2,4
Zeytinburnu	292313	-0,3
TOTAL	14160 467	

Table 3.3: Population and Annual growth rate of population (%) [46]

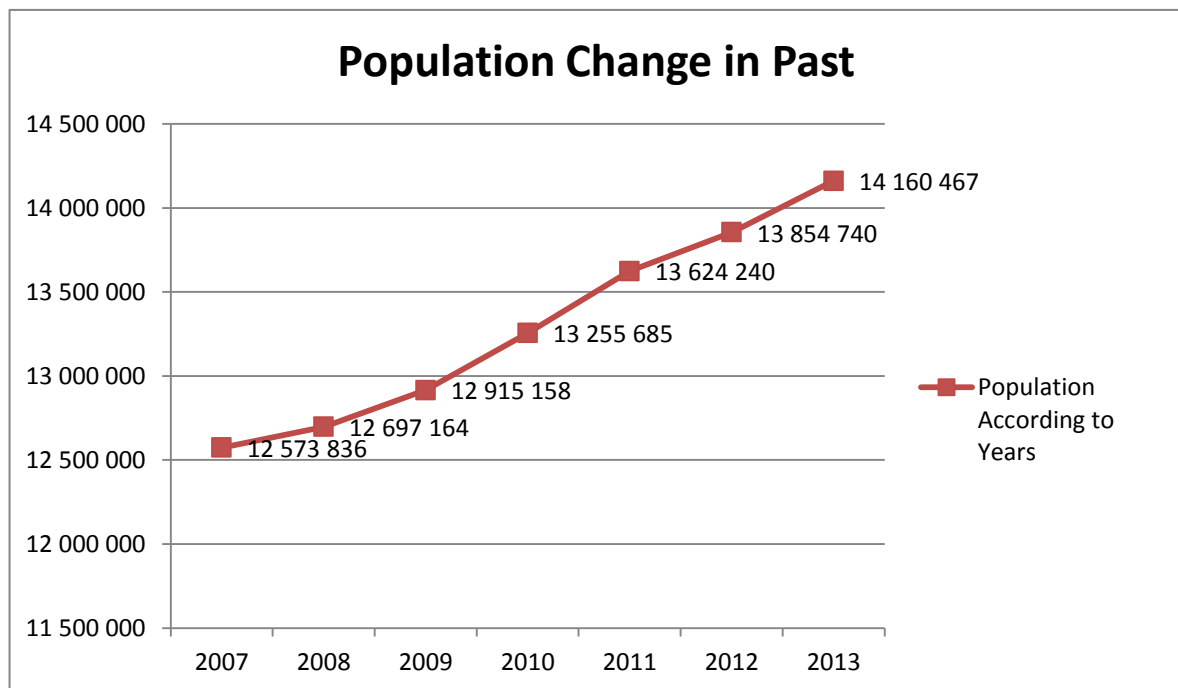


Figure 3.3: Population increase between 2007-2013 [46]

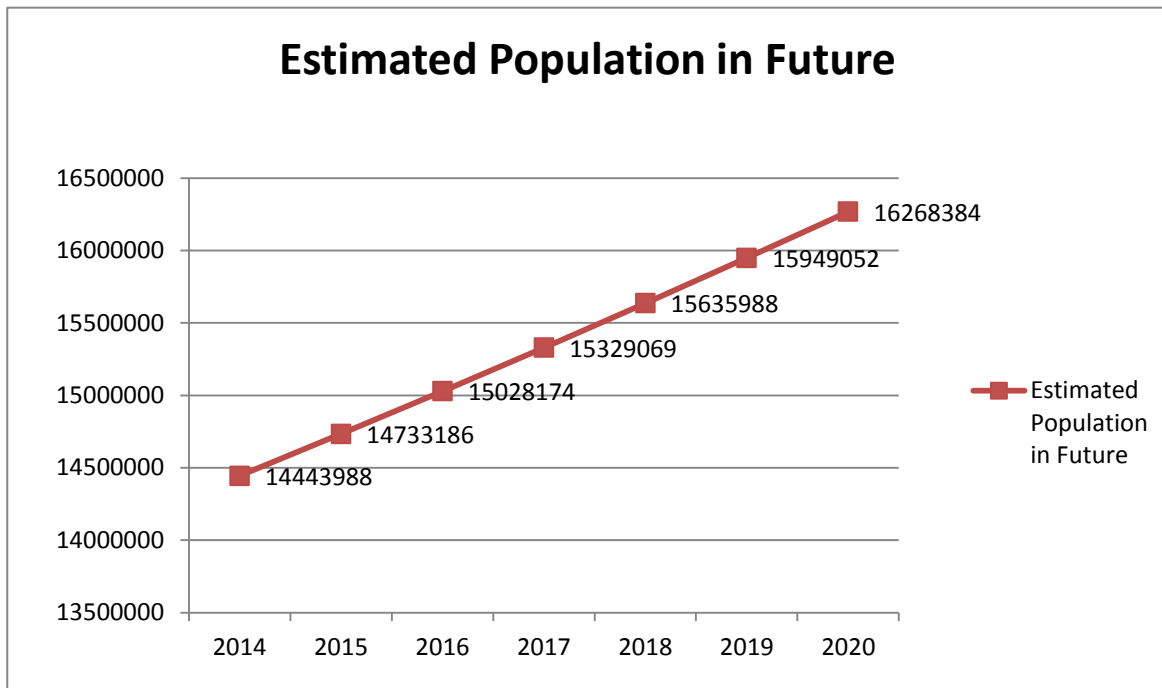


Figure 3.4: Expected population increase in İstanbul

Figure 3.5 shows the roads in İstanbul [47]. First row of each yellow box shows the total number of passenger cars that use that particular road. Others show heavy vehicles, trucks and motorcycles. Bold number shows the total amount of all type of vehicles that use these roads. Total amount of roads which is shown below is 310 km. It considers the main roads and intersection points.

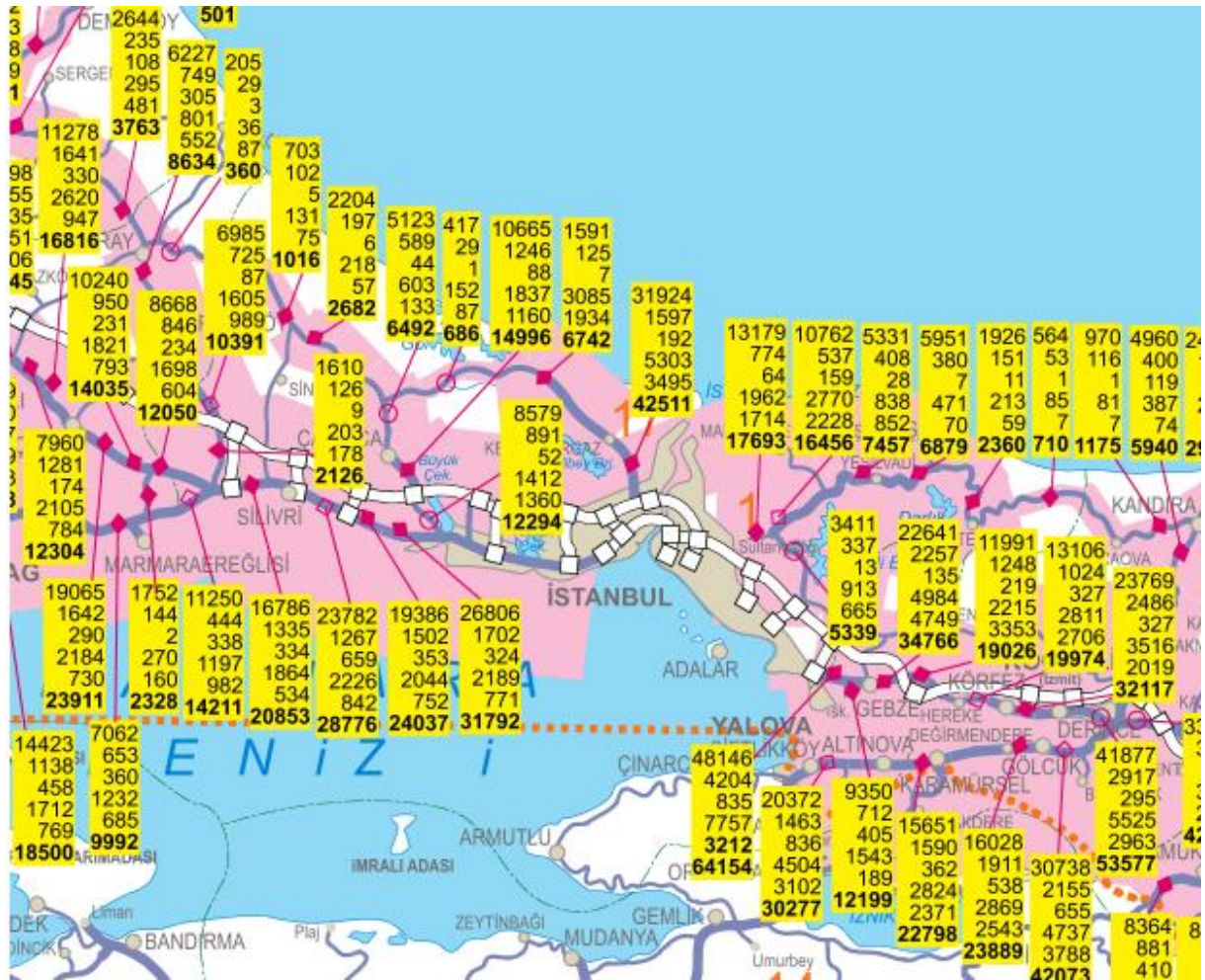


Figure 3.5: Main Arterial roads and traffic density of these roads[47]

The traffic density is calculated via the methods explained below. These methods are used by General Directorate of Highways.

Automatic vehicle classification counts (OTSS1) are on 1082 points, in every season for at least 7 days and 24 hours by classification devices [47].

Automatic vehicle classification counts (OTSS2) which were realized on 2 permanent stations by Weigh-In-Motion (WIM) devices [47].

Automatic vehicle classification counts (OTSS3) were installed on 193 locations all around Turkey [47].

There are many types of cars for different purposes. Vehicles are divided into 5 different groups [47].

- Passenger car, pick-up etc. vehicles with maximum 3.5 tons loaded weight and vehicles with 8-14 person passenger capacity.
- Medium Goods Vehicles with 14-25 passenger capacity and trucks with 3.5 -10 tons loaded weight.
- Bus with more than 25 passenger capacity.
- Truck
- Articulated truck

In this study, we just consider the number of passenger cars and Table 3.4 [48] shows the changes in the amount of cars according to the years.

Years	Number of Cars	Change in number of cars	Percentage of increase
2005	1590283		
2006	1657320	67037	4.2154
2007	1711773	54453	3.2856
2008	1758745	46972	2.7440
2009	1775335	16590	0.9432
2010	1821694	46359	2.6112
2011	1907782	86088	4.7257
2012	1963371	55589	2.9138
2013	2146257	182886	9.3148

Table 3.4: Number of Cars in İstanbul According to Years

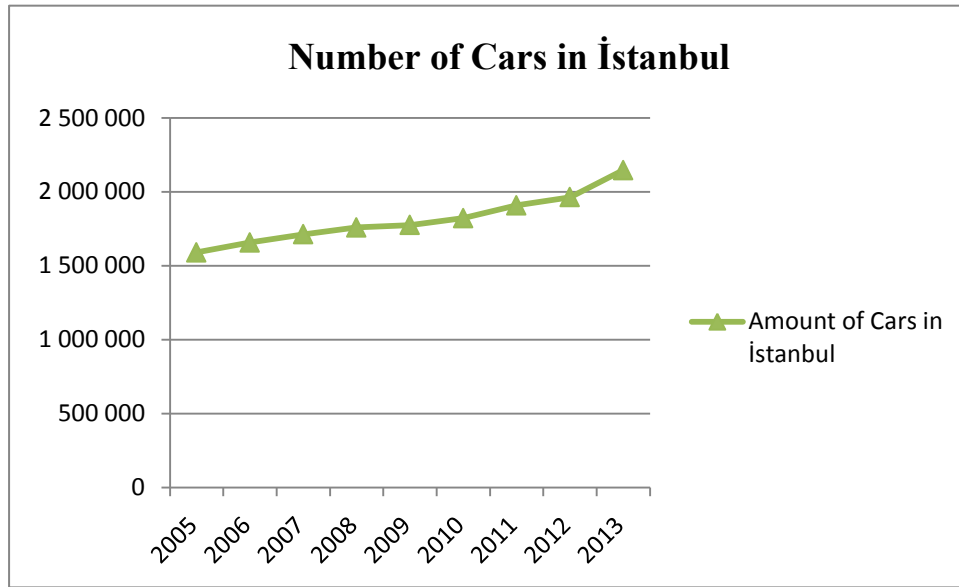


Figure 3.6: Number of Cars in İstanbul According to Years

Average increase in the number of cars according to years in İstanbul is approximately %3. We can calculate the estimated number of cars in İstanbul from 2013 to 2020 with this average increase rate. We assume that each year the amount of cars increases approximately %3.

Years	Number of Cars
2014	2,228,765
2015	2,314,444
2016	2,403,417
2017	2,495,811
2018	2,591,756
2019	2,691,390
2020	2,794,854

Table 3.5: Estimated Number of Cars in İstanbul According to Years in Future

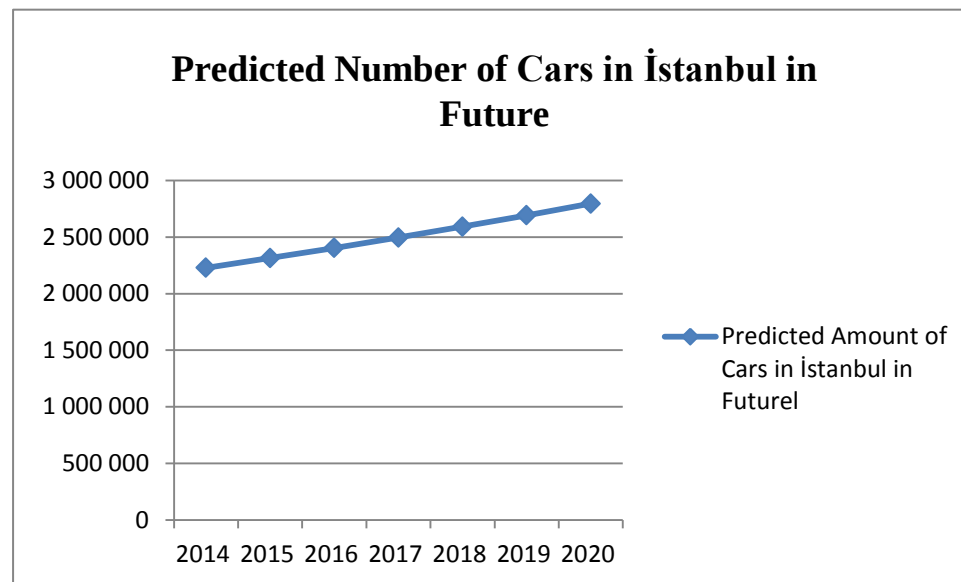


Figure 3.7: Estimated Number of Cars in İstanbul According to Years in Future

Most of the vehicles use fossil fuels currently. We expect that those number will decrease and cars replaced by environmental friendly cars in the future

Number of road passenger vehicles by kind of fuel used:

	2008	2009	2010	2011	2012
Gas	1266113	1227782	1171541	1129963	1109418
Diesel	1095365	1162184	1280598	1446154	1593030
LPG	216817	240431	259032	275992	294150
Unknown	107461	90806	83065	75541	68867

Table 3.6: Fuel type of cars according to years [49]

3.4. Gas Emission Calculations

Emission standards are limits to the amount of pollutants that can be released into the environment. European emission standards define the acceptable limits for exhaust emissions of new vehicles in Europe. Vehicles divided into categories in order to evaluate them according to their gas emissions. The light category of vehicles covers road vehicles under 3.5 tons such as passenger cars. Standards vary depending on fuel type of the vehicle such as petrol or diesel.

The first Euro standard, Euro 1 determined in 1992-93, and these requirements forced manufacturers to install three-way catalytic converters in petrol vehicles. Since the Euro 1 value released, the emissions limits have been decreasing and the standards have subsequently been updated several times. Euro 2 standards decided in 1996 for passenger cars. Euro4 regulation adopted in December 2006 established the currently applicable Euro standards. Euro 5 standard applies to the approval of new vehicles as of September 2009, and to the sale of all new vehicles as from January 2011, while the Euro 6 standard will apply from September 2014 and September 2015 onwards. Table 3.7 shows the evolving standards for passenger cars for the substances of main concern. The standards for light vehicles are defined by driving distance and expressed in milligrams per kilometer (mg/km) [50].

Emission Factors (g/km)										
Emission Technology	CO		Nox		Nox+HC		HC		PM	
	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel
EURO1	2,7	2,7			0,97	0,97				0,14
EURO2	2,2	1			0,5	0,7				0,08
EURO 3	2,3	0,6	0,15	0,5		0,56	0,2			0,05
EURO 4	1	0,5	0,08	0,25		0,3	0,1			0,025
EURO 5	1	0,5	0,06	0,18		0,23	0,1		0,005	0,005
EURO 6	1	0,5	0,06	0,08		0,17	0,1		0,005	0,005

Table 3.7: Emission according to EURO standards

The table which is written above shows the emission factors for personal vehicles. These coefficients are determined by European Union. Euro4 standards can be acceptable until 2014. Turkey use Euro 4 standards now [51]. In the future, the aim is decreasing the gas emissions to the level of Euro 6.

3.4.1. Gas Emission Calculations of Main Roads in Istanbul

Number of passenger cars in İstanbul reached to more than two million. Effects of this huge amount must be analyzed carefully to see the current situation to take precaution if it is necessary.

Formula for gas emission calculations is

$$\text{Gas emission} = \text{length of the road (km)} \times \text{gas emission per km (gr/km)} \quad (3.3)$$

All of the tables below created with using this formula. Each value shows the gas emission from only one car for the given road.



Figure 3.8: Main arterial roads in İstanbul [47]

				CO		NO _x +HC		PM
	KKNO	Part No	Length (Km)	Petrol	Diesel	Petrol	Diesel	Diesel
Istanbul	100-04	1	11	29,7	29,7	10,67	10,67	1,54
Istanbul	100-04	2	12	32,4	32,4	11,64	11,64	1,68
Istanbul	100-04	3	11	29,7	29,7	10,67	10,67	1,54
Istanbul	100-04	4	8	21,6	21,6	7,76	7,76	1,12
Istanbul	100-04	5	10	27	27	9,7	9,7	1,4
Istanbul	110-05	0	9	24,3	24,3	8,73	8,73	1,26
Istanbul	567-02	1	8	21,6	21,6	7,76	7,76	1,12
Istanbul	567-02	2	15	40,5	40,5	14,55	14,55	2,1
Istanbul	569-01	1	10	27	27	9,7	9,7	1,4
Istanbul	569-01	2	7	18,9	18,9	6,79	6,79	0,98
Istanbul	569-01	3	10	27	27	9,7	9,7	1,4
Istanbul	020-05	1	18	48,6	48,6	17,46	17,46	2,52
Istanbul	020-05	2	26	70,2	70,2	25,22	25,22	3,64
Istanbul	020-06	1	26	70,2	70,2	25,22	25,22	3,64
Istanbul	020-06	2	23	62,1	62,1	22,31	22,31	3,22
Istanbul	020-06	3	9	24,3	24,3	8,73	8,73	1,26
Istanbul	020-07	1	19	51,3	51,3	18,43	18,43	2,66
Istanbul	020-07	2	9	24,3	24,3	8,73	8,73	1,26
Istanbul	020-07	3	16	43,2	43,2	15,52	15,52	2,24
Istanbul	020-07	4	14	37,8	37,8	13,58	13,58	1,96
Istanbul	020-08	1	19	51,3	51,3	18,43	18,43	2,66

Table 3.8: Gas emissions (gr/km) per car on roads according to EURO 1 standards

				CO		NOx+HC		PM
	KKNO	Part No	Length (Km)	Petrol	Diesel	Petrol	Diesel	Diesel
Istanbul	100-04	1	11	24,2	11	5,5	7,7	0,88
Istanbul	100-04	2	12	26,4	12	6	8,4	0,96
Istanbul	100-04	3	11	24,2	11	5,5	7,7	0,88
Istanbul	100-04	4	8	17,6	8	4	5,6	0,64
Istanbul	100-04	5	10	22	10	5	7	0,8
Istanbul	110-05	0	9	19,8	9	4,5	6,3	0,72
Istanbul	567-02	1	8	17,6	8	4	5,6	0,64
Istanbul	567-02	2	15	33	15	7,5	10,5	1,2
Istanbul	569-01	1	10	22	10	5	7	0,8
Istanbul	569-01	2	7	15,4	7	3,5	4,9	0,56
Istanbul	569-01	3	10	22	10	5	7	0,8
Istanbul	020-05	1	18	39,6	18	9	12,6	1,44
Istanbul	020-05	2	26	57,2	26	13	18,2	2,08
Istanbul	020-06	1	26	57,2	26	13	18,2	2,08
Istanbul	020-06	2	23	50,6	23	11,5	16,1	1,84
Istanbul	020-06	3	9	19,8	9	4,5	6,3	0,72
Istanbul	020-07	1	19	41,8	19	9,5	13,3	1,52
Istanbul	020-07	2	9	19,8	9	4,5	6,3	0,72
Istanbul	020-07	3	16	35,2	16	8	11,2	1,28
Istanbul	020-07	4	14	30,8	14	7	9,8	1,12
Istanbul	020-08	1	19	41,8	19	9,5	13,3	1,52

Table 3.9: Gas emissions (gr/km) on roads per car according to EURO 2 standards

				CO		NO _x		NO _x +HC		PM
	KKNO	Part No	Length (Km)	Petrol	Diesel	Petrol	Diesel	Diesel	Petrol	Diesel
Istanbul	100-04	1	11	25,3	6,6	1,65	5,5	6,16	2,2	0,55
Istanbul	100-04	2	12	27,6	7,2	1,8	6	6,72	2,4	0,6
Istanbul	100-04	3	11	25,3	6,6	1,65	5,5	6,16	2,2	0,55
Istanbul	100-04	4	8	18,4	4,8	1,2	4	4,48	1,6	0,4
Istanbul	100-04	5	10	23	6	1,5	5	5,6	2	0,5
Istanbul	110-05	0	9	20,7	5,4	1,35	4,5	5,04	1,8	0,45
Istanbul	567-02	1	8	18,4	4,8	1,2	4	4,48	1,6	0,4
Istanbul	567-02	2	15	34,5	9	2,25	7,5	8,4	3	0,75
Istanbul	569-01	1	10	23	6	1,5	5	5,6	2	0,5
Istanbul	569-01	2	7	16,1	4,2	1,05	3,5	3,92	1,4	0,35
Istanbul	569-01	3	10	23	6	1,5	5	5,6	2	0,5
Istanbul	020-05	1	18	41,4	10,8	2,7	9	10,08	3,6	0,9
Istanbul	020-05	2	26	59,8	15,6	3,9	13	14,56	5,2	1,3
Istanbul	020-06	1	26	59,8	15,6	3,9	13	14,56	5,2	1,3
Istanbul	020-06	2	23	52,9	13,8	3,45	11,5	12,88	4,6	1,15
Istanbul	020-06	3	9	20,7	5,4	1,35	4,5	5,04	1,8	0,45
Istanbul	020-07	1	19	43,7	11,4	2,85	9,5	10,64	3,8	0,95
Istanbul	020-07	2	9	20,7	5,4	1,35	4,5	5,04	1,8	0,45
Istanbul	020-07	3	16	36,8	9,6	2,4	8	8,96	3,2	0,8
Istanbul	020-07	4	14	32,2	8,4	2,1	7	7,84	2,8	0,7
Istanbul	020-08	1	19	43,7	11,4	2,85	9,5	10,64	3,8	0,95

Table 3.10: Gas emissions (gr/km) on roads per car according to EURO 3 standards

				CO		NOx		NOx+HC	HC	PM
	KKNO	Part No	Length (Km)	Petrol	Diesel	Petrol	Diesel	Diesel	Petrol	Diesel
Istanbul	100-04	1	11	11	5,5	0,88	2,75	3,3	1,1	0,275
Istanbul	100-04	2	12	12	6	0,96	3	3,6	1,2	0,3
Istanbul	100-04	3	11	11	5,5	0,88	2,75	3,3	1,1	0,275
Istanbul	100-04	4	8	8	4	0,64	2	2,4	0,8	0,2
Istanbul	100-04	5	10	10	5	0,8	2,5	3	1	0,25
Istanbul	110-05	0	9	9	4,5	0,72	2,25	2,7	0,9	0,225
Istanbul	567-02	1	8	8	4	0,64	2	2,4	0,8	0,2
Istanbul	567-02	2	15	15	7,5	1,2	3,75	4,5	1,5	0,375
Istanbul	569-01	1	10	10	5	0,8	2,5	3	1	0,25
Istanbul	569-01	2	7	7	3,5	0,56	1,75	2,1	0,7	0,175
Istanbul	569-01	3	10	10	5	0,8	2,5	3	1	0,25
Istanbul	020-05	1	18	18	9	1,44	4,5	5,4	1,8	0,45
Istanbul	020-05	2	26	26	13	2,08	6,5	7,8	2,6	0,65
Istanbul	020-06	1	26	26	13	2,08	6,5	7,8	2,6	0,65
Istanbul	020-06	2	23	23	11,5	1,84	5,75	6,9	2,3	0,575
Istanbul	020-06	3	9	9	4,5	0,72	2,25	2,7	0,9	0,225
Istanbul	020-07	1	19	19	9,5	1,52	4,75	5,7	1,9	0,475
Istanbul	020-07	2	9	9	4,5	0,72	2,25	2,7	0,9	0,225
Istanbul	020-07	3	16	16	8	1,28	4	4,8	1,6	0,4
Istanbul	020-07	4	14	14	7	1,12	3,5	4,2	1,4	0,35
Istanbul	020-08	1	19	19	9,5	1,52	4,75	5,7	1,9	0,475

Table 3.11: Gas emissions (gr/km) on roads per car according to EURO 4 standards

				CO		NO _x		NO _x + HC	HC	PM	
	KKNO	Part No	Length (Km)	Petrol	Diesel	Petrol	Diesel	Diesel	Petrol	Petrol	Diesel
Istanbul	100-04	1	11	11	5,5	0,66	1,98	2,53	1,1	0,055	0,055
Istanbul	100-04	2	12	12	6	0,72	2,16	2,76	1,2	0,06	0,06
Istanbul	100-04	3	11	11	5,5	0,66	1,98	2,53	1,1	0,055	0,055
Istanbul	100-04	4	8	8	4	0,48	1,44	1,84	0,8	0,04	0,04
Istanbul	100-04	5	10	10	5	0,6	1,8	2,3	1	0,05	0,05
Istanbul	110-05	0	9	9	4,5	0,54	1,62	2,07	0,9	0,045	0,045
Istanbul	567-02	1	8	8	4	0,48	1,44	1,84	0,8	0,04	0,04
Istanbul	567-02	2	15	15	7,5	0,9	2,7	3,45	1,5	0,075	0,075
Istanbul	569-01	1	10	10	5	0,6	1,8	2,3	1	0,05	0,05
Istanbul	569-01	2	7	7	3,5	0,42	1,26	1,61	0,7	0,035	0,035
Istanbul	569-01	3	10	10	5	0,6	1,8	2,3	1	0,05	0,05
Istanbul	020-05	1	18	18	9	1,08	3,24	4,14	1,8	0,09	0,09
Istanbul	020-05	2	26	26	13	1,56	4,68	5,98	2,6	0,13	0,13
Istanbul	020-06	1	26	26	13	1,56	4,68	5,98	2,6	0,13	0,13
Istanbul	020-06	2	23	23	11,5	1,38	4,14	5,29	2,3	0,115	0,115
Istanbul	020-06	3	9	9	4,5	0,54	1,62	2,07	0,9	0,045	0,045
Istanbul	020-07	1	19	19	9,5	1,14	3,42	4,37	1,9	0,095	0,095
Istanbul	020-07	2	9	9	4,5	0,54	1,62	2,07	0,9	0,045	0,045
Istanbul	020-07	3	16	16	8	0,96	2,88	3,68	1,6	0,08	0,08
Istanbul	020-07	4	14	14	7	0,84	2,52	3,22	1,4	0,07	0,07
Istanbul	020-08	1	19	19	9,5	1,14	3,42	4,37	1,9	0,095	0,095

Table 3.12: Gas emissions (gr/km) on roads per car according to EURO 5 standards

				CO		NOx		NOx+ HC	HC	PM	
	KKNO	Part No	Length (Km)	Petrol	Diesel	Petrol	Diesel	Diesel	Petrol	Petrol	Diesel
Istanbul	100-04	1	11	11	5,5	0,88	1,98	1,87	1,1	0,055	0,055
Istanbul	100-04	2	12	12	6	0,96	2,16	2,04	1,2	0,06	0,06
Istanbul	100-04	3	11	11	5,5	0,88	1,98	1,87	1,1	0,055	0,055
Istanbul	100-04	4	8	8	4	0,64	1,44	1,36	0,8	0,04	0,04
Istanbul	100-04	5	10	10	5	0,8	1,8	1,7	1	0,05	0,05
Istanbul	110-05	0	9	9	4,5	0,72	1,62	1,53	0,9	0,045	0,045
Istanbul	567-02	1	8	8	4	0,64	1,44	1,36	0,8	0,04	0,04
Istanbul	567-02	2	15	15	7,5	1,2	2,7	2,55	1,5	0,075	0,075
Istanbul	569-01	1	10	10	5	0,8	1,8	1,7	1	0,05	0,05
Istanbul	569-01	2	7	7	3,5	0,56	1,26	1,19	0,7	0,035	0,035
Istanbul	569-01	3	10	10	5	0,8	1,8	1,7	1	0,05	0,05
Istanbul	020-05	1	18	18	9	1,44	3,24	3,06	1,8	0,09	0,09
Istanbul	020-05	2	26	26	13	2,08	4,68	4,42	2,6	0,13	0,13
Istanbul	020-06	1	26	26	13	2,08	4,68	4,42	2,6	0,13	0,13
Istanbul	020-06	2	23	23	11,5	1,84	4,14	3,91	2,3	0,115	0,115
Istanbul	020-06	3	9	9	4,5	0,72	1,62	1,53	0,9	0,045	0,045
Istanbul	020-07	1	19	19	9,5	1,52	3,42	3,23	1,9	0,095	0,095
Istanbul	020-07	2	9	9	4,5	0,72	1,62	1,53	0,9	0,045	0,045
Istanbul	020-07	3	16	16	8	1,28	2,88	2,72	1,6	0,08	0,08
Istanbul	020-07	4	14	14	7	1,12	2,52	2,38	1,4	0,07	0,07
Istanbul	020-08	1	19	19	9,5	1,52	3,42	3,23	1,9	0,095	0,095

Table 3.13: Gas emissions (gr/km) on roads per car according to EURO 6 standards

3.4.1.1. Carbon Monoxides (CO) Emissions

Carbon Monoxide is produced because of incomplete combustion. It is a poisonous gas which is colorless and odorless. It prevents delivering oxygen to bodily tissues. Vehicles which use fossil fuels are reason of the CO emissions in the first place. It is also indicated by a higher amount of carbon dioxide (CO₂) in the exhaust gases.

Causes of High Carbon Monoxide (CO):

- Dirty Air Filter
- Faulty Oxygen Sensor (O₂ Sensor)
- Defective Manifold Absolute Pressure (MAP) Sensor
- Defective Throttle Position Sensor (TPS)
- Defective Engine Coolant Temperature (ECT) Sensor

Figure 3.9 shows the amount of CO emission changes according to euro standards and years in İstanbul [52].

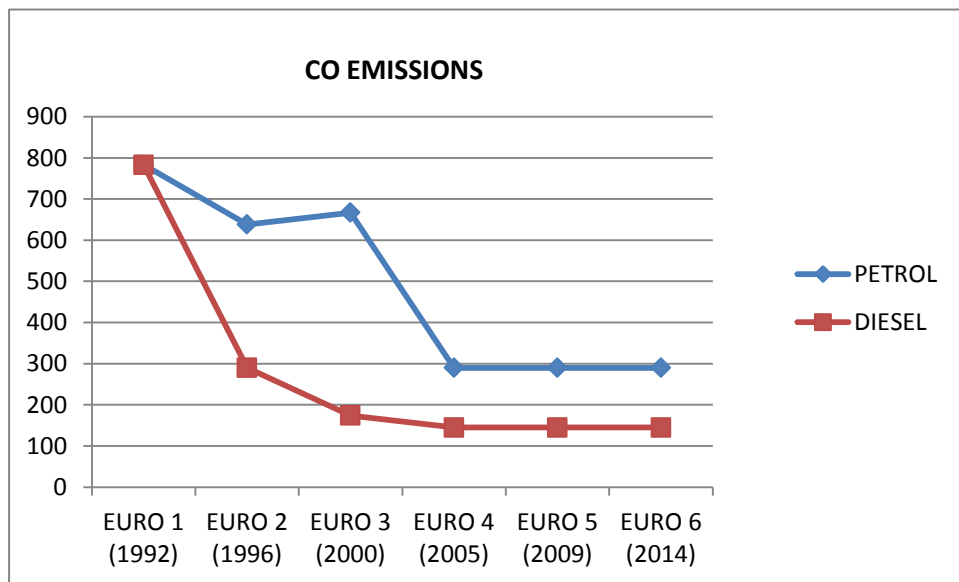


Figure 3.9: CO emissions according to EURO standards

3.4.1.2. NO_x Emissions

NO_x is a generic term for mono-nitrogen oxides NO and NO₂ (nitric oxide and nitrogen dioxide). They are produced from the reaction of nitrogen and oxygen gases in the air during combustion, especially at high temperatures [53].

Causes of High NO_x Emissions:

- Too lean of fuel mixture
- Bad cooling system in engine
- Malfunction of the electronic spark control (ESC), and knock sensor
- Contaminated or bad catalytic converter

Figure 3.10 shows the amount of NO_x emission change according to euro standards and years in İstanbul.

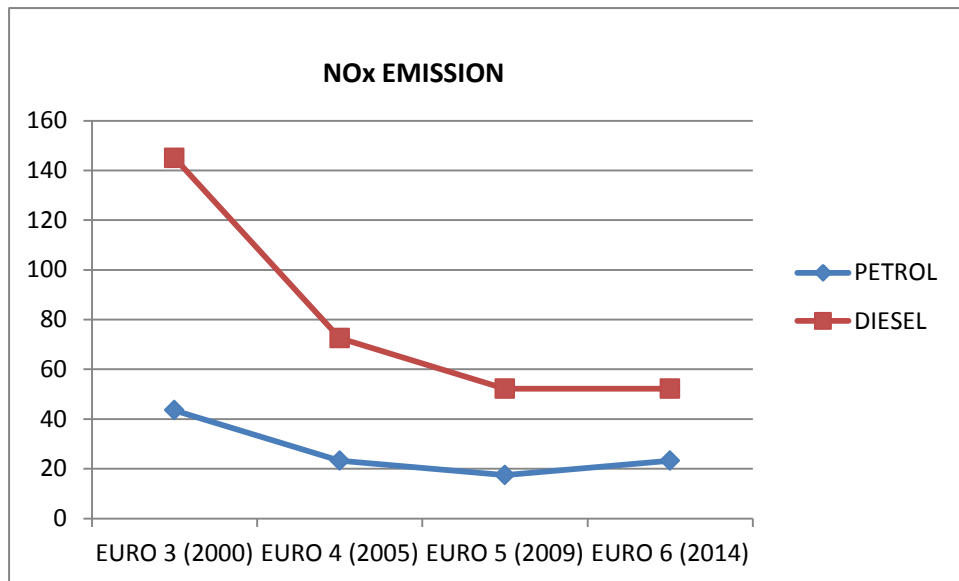


Figure 3.10: NO_x emissions according to EURO standards

3.4.1.3. Particulate Matter (PM)

Atmospheric particulate matter is also known as particulates or particulate matter (PM). They are tiny pieces of solid or liquid matter associated with the Earth's atmosphere. Human activities, such as the burning of fossil fuels in vehicles, power plants and various industrial processes also generate significant amounts of particulates [54]. There is no research of PM emission of cars from 1992 to 2005.

From 1992 to 2014, Figure 3.11 shows the emission of PM in İstanbul.

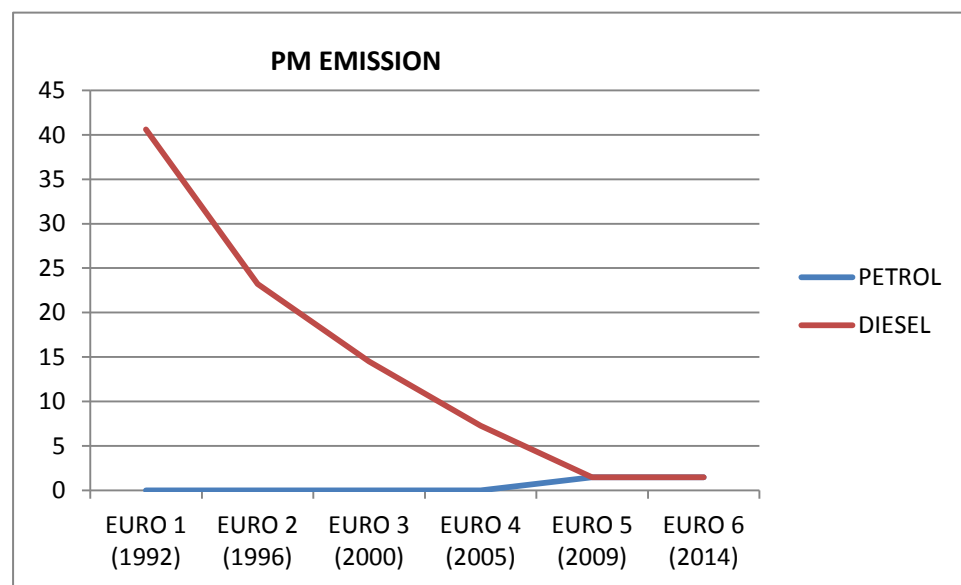


Figure 3.11: PM emissions according to EURO standards

3.4.1.4. NO_x +HC EMISSION

From Euro 1 to Euro 2 (1992-1996) nitrogen oxides and hydrocarbons are evaluated together. With euro 3 standards, they are started to evaluated separately. Figure 3.12 shows the amount of NO_x +HC emission change according to euro standards and years in İstanbul.

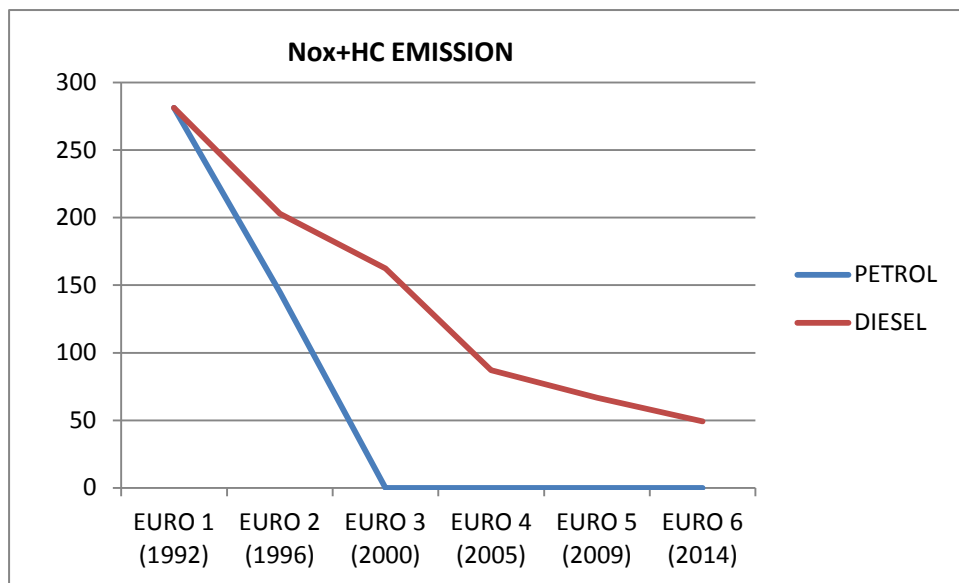


Figure 3.12: NO_x + HC emissions according to EURO standards

3.4.1.5. Hydrocarbons (HC)

Incomplete combustion leads to the presence of hydrocarbons (HC).

Causes of hydrocarbons [55]:

- Unnormal engine temperature
- Insufficient spark duration.

- Contaminated or restricted catalytic converter
- Extremely lean fuel mixture that causes misfiring.

From 1992 to 2014, Figure 3.13 shows the emission of HC in İstanbul

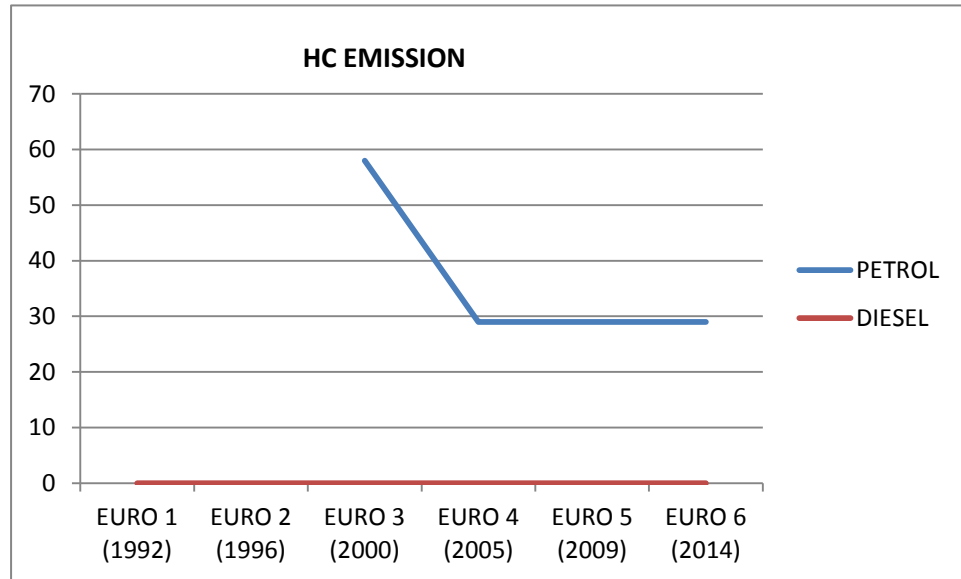


Figure 3.13: HC emissions according to EURO standards

3.4.1.6. CO₂ Emission

Some of the cars manufacturers calculate their cars gas emissions. Values depend on the car model, their fuel type and engine. These gas emissions calculated under special conditions [56].

Average amount of CO₂ emission is:

1 liter petrol = 2.3 kilograms of carbon dioxide

1 liter LPG = 1.5 kilograms of carbon dioxide

1 liter diesel = 2.7 kilograms of carbon dioxide

There is no standard coefficient for CO₂ emission for vehicles.

Chapter 4

CHARGING STATIONS AND CHARGER TYPES

Developments of vehicles which work with electricity create need for electric charge stations. Evolvement of electric vehicles cannot be separated from charging infrastructures. Lack of infrastructure is one of the obstacles to adoption of electric vehicles because many drivers are unwilling to buy electric cars without proper electric charge station distribution.

An electric vehicle charger recharges the battery in an electric vehicle or a plug-in hybrid vehicle. EV chargers can be installed in houses, office, shopping centers, parking garages and public places to enable people to charge their cars.

4.1 Types of Cars

4.1.1 Internal Combustion Engine Vehicle (ICE)

Internal combustion engine depends on combustion of a chemical fuel. They use liquid fossil fuels such as gasoline, diesel, ethanol, or biodiesel. When fuel burns, it sets related parts in rotating motion, enabling vehicle to move. Majority of personal vehicles today have an internal combustion engine. They are main contributor to environment pollution with releasing harmful gases.

4.1.2 Grid Enabled Vehicle (GEV)

This type of cars can plug in to an external power source to recharge. GEVs use electricity to provide some of their power. Grid-enabled vehicles (GEVs), such as electric vehicles (EVs) and plug-in (PHEVs) can contribute environmental and energy issues by using electricity instead of fossil fuels [57].

4.1.3 Electric Vehicle (EV)

An electric car has one electric motor or more, using electrical energy stored in batteries or another energy storage device. This type of cars runs on electricity only. This type of vehicles use electricity as fuel. Due to the price differences between electricity prices and fossil fuels, it is expected that usage of electric vehicles will increase in the future [58].

4.1.4 Plug-in Hybrid Electric Vehicle (PHEV)

Plug-in Hybrid Electric Vehicles (PHEVs) are electric cars with high capacity batteries that can be charged by plugging them into an electrical outlet. These vehicles, like other Hybrid Electric Vehicles (HEVs) have an onboard internal combustion engine that charges batteries or otherwise provides electricity to an electric motor. PHEVs use about 40 to 60 percent less petroleum than conventional vehicles [59].

Electric mode can be used for short trips. Driver can switch to mode combined gas/electric once the battery runs low or if higher engine performance is needed [60]. Their batteries are higher than hybrid vehicles and this makes them more expensive than hybrid

cars. Example of PHEV is Chevrolet Volt [61], Fisker Karma [62], Toyota Prius Plug-in Hybrid [63].

4.1.5 Hybrid Electric Vehicles (HEV)

Hybrid vehicles (HEVs) rely on two or more energy systems. It works through a combination of an internal combustion engine, a bank of batteries, and an electric motor. It has the benefits of combustion engines and electric motors and can be configured to meet different objectives such as improved fuel economy, increased power and reduces gas emissions.

Some of HEVs use their internal combustion engine to generate electricity and some of them run on just fuel and do not plug in to an electrical outlet to recharge the battery. Example of HEV is Toyota Prius, Ford Fusion Hybrid [63].

4.1.6 Battery Electric Vehicle (BEV)

A battery electric vehicle (BEV) is a type of electric vehicle that uses chemical energy stored in rechargeable battery packs. It has no internal combustion engine or fuel tank. Battery electric vehicle must be plugged in to obtain energy to drive the vehicle and has a range limited by the battery pack. They called as pure EV because they have no gas emission. Currently this type of model is small cars with limited ranges because of the batteries. They approximately have a range between 95 and 160 kilometers. Examples of BEVs are Nissan Leaf, Mitsubishi iMiEV, Arcimoto, Brammo Enertia, Ford Focus Electric [63].

4.1.7 Energy Consumption Of Cars

The energy consumption of an electric car will be determined by its efficiency and how it is driven. Charging of cars will be cheaper than a gallon of gas in current situation. Energy use per km is difficult to estimate because energy consumption of cars change according to driving style. Energy use per km depends on other parameters such as the efficiency of the engine, the vehicle weight and size, tyres, aerodynamics etc. [64].

At the end of the 2011, There are 1 907 782 personal cars in İstanbul [49]. In 2014, it is estimated that there are more than 2 million personal cars. Electricity consumption of PHEV cars changes between 0.10 kwh/km and 0.20 kwh/km. Moreover, EVs/BEVs consumption is changes between 0.18 kwh/km and 0.50 kwh/km but it depends on the driving style and condition [65].

4.2 Cost To Charge An Electric Car

The cost of charging the battery depends on the price paid per kWh of electricity. In Turkey, average electricity price is 0.15 TL/Kwh [66]. It means a car can go up to 100 km and it costs 2.7 TL. The cost of electricity in city will affect total charge price, and the way you drive your EV will affect how many km you get per charge.

4.3 Types Of Chargers

Charging equipment for all-electric vehicles is classified by the rate at which the batteries are charged. EV Chargers or car charging stations classified in 3 types of levels.

Level 1 has wide range of uses. Its installation cost is low. It typically takes between 8 to 14 hours to fully charge a vehicle. It is the most common type of charger. The biggest disadvantage is the length of time it takes to recharge a vehicle [67].

Level 2 is used for overnight and opportunity charging at public locations. It increases the charge power and decreases the full charge time down to 4-8 hours. The main advantage of this charging is speed. The disadvantage of this type of charging is managing the heat that is produced in the battery through the charging process [67].

Level 3, direct-current (DC) fast charging equipment, enables rapid charging. Fast charging, requires very high levels of voltage and current [67].

Tables 4.1 summarize the power need and charging time:

Charging Time	Power Supply	Voltage	Max Current
20-30 min	Direct Current(50kW)	400-500 VDC	100-125 A
20-30 min	Three Phase-43kW	400 VAC	63 A
1-2 hours	Three Phase-24kW	400 VAC	32 A
2-3 hours	Three Phase-10Kw	400 VAC	32A
3-4 hours	Single phase-7Kw	230 VAC	16A
6-8 hours	Single phase-3,3 Kw	230 VAC	16 A

Table 4.1: Charging times changes according to charge type

4.4 Electric Charging Stations

4.4.1 Charge Stations

Charge stations are the places that owner of electric vehicles can charge their cars. They may consist of different or same level chargers. First station was built in Australia in 2010 [68]. Since then it spread all around the world. Non-residential slow charging points

reached about 50,000 amount in the U.S., Europe, Japan and China until December 2012 [69]. With developments in technology, fast chargers also take their places in charge stations.

4.4.2 Battery Swap Stations

Battery swapping is another idea for charge stations. Automated battery-switching station (also called Quick drop Stations) can complete a battery swap in less than one minute. It is faster than charging a battery or refueling conventional cars. Electric car is perfectly practical in this way. In this system, drivers do not own the battery. They just pay for the energy they use. Also, it makes car cheaper.

The first “Quick drop” battery-swap station in Europe opened in Gladsaxe in Denmark in 2011 but this concept proposed in 1986 at first [70]. Swap stations are quick and easy to use, efficient and automated. The driver simply needs to swipe a magnetic card for identification, and then the swap system will operate automatically with using robots. Drivers do not have to leave their cars in this process. Cars are full and ready to go in a short time.

The main battery selection criteria are: type, size, weight, cost, life cycle, efficiency, maturity, availability, and dependability [71].

Type of Batteries are [72]:

- Lithium-ion
- Lithium iron phosphate
- Lithium-titanate
- Lead acid batteries NiCd - Largely superseded by NiMH
- Nickel metal hydride (NiMH)
- Nickel iron battery

- Zinc-air battery
- Molten salt battery
- Zinc-bromine flow batteries
- Vanadium redox batteries

4.5 Cost of Chargers

Price of chargers increase according to their charging speed. From fast charger to slow charger, prices change drastically. A standard electric vehicle charger 1800 watts from a standard 120 volt AC outlet starts at \$600 and for a higher output of around 5000 watts from a 240 volt AC outlet, a chargers price increases to approximately \$5,000 [73].

For the charge stations, place which the station is built is also another source of cost. Infrastructure and construction area costs change according to wealthness of the district.

4.6 Existing Charging Stations In Istanbul

Istanbul already have small amount of charging stations. It is expected increase amount of them with the increment of electric vehicles. Both private sector and government have already started to make investments to charging stations.



Figure 4.1: Private charging station locations

Charging stations in European region in İstanbul [74]:

1. Carrefour avm- Haramidere
2. Atatürk havalimanı dış hatlar otoparkı
3. Atatürk havalimanı iç hatlar otoparkı
4. Forum İstanbul AVM
5. TNT güneşli
6. Başak otoparkı- Güneşli-Bağcılar
7. PTT Osmaniye
8. Marmara Forum AVM Bakırköy
9. T-Park Muratpaşa/Fatih
10. T-Park İskenderpaşa/Fatih(yapım aşamasında)
11. Aras Kargo-Sarıyer
12. T-Park Kağıthane

13. İspark Cihangir Katlı Otoparkı-Beyoğlu

Charging stations in Anatolian region in İstanbul:

14. G2M Dağıtım Pazarlama-Sancaktepe

15. BD oto şarj istasyonu -Alidede Cad. No: 4 Koşuyolu

16. Carrefour AVM - İçerenköy

Some of the chargers put in to parking garages in different districts of İstanbul. İspark owned this kind of charging stations

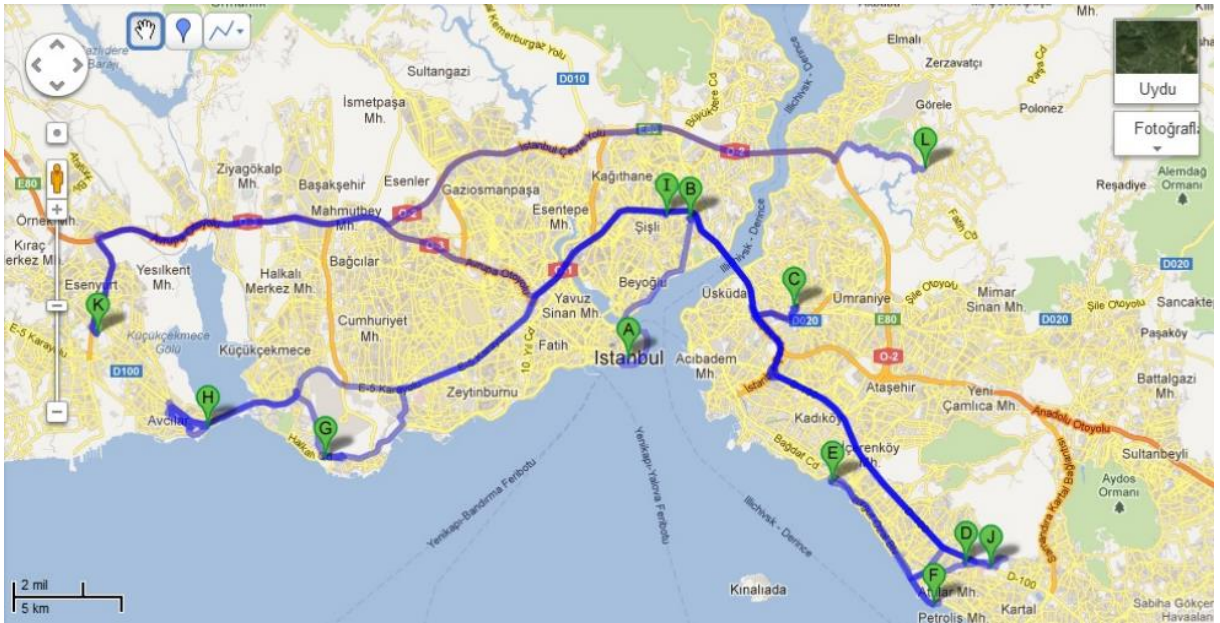


Figure 4.2: Private Charging station locations

İspark Charge Stations Combined with Parking Garages are listed below [75]

1. İBB Balmumcu Yeraltı Katlı Otopark Şarj Noktası
2. İBB Anadolu Yakası Çamlıca Sosyal Tesisleri Şarj Noktası
3. İBB Anadolu Yakası Çamlıca Şarj Noktası

4. İBB Anadolu Yakası İçerenköy Şarj Noktası
5. İBB Anadolu Yakası Bostancı Şarj Noktası
6. İBB Anadolu Yakası Kartal Şarj Noktası
7. İBB Avrupa Yakası Florya Sosyal Tesisleri Şarj Noktası
8. İBB Avrupa Yakası Avcılar Sosyal Tesisleri Şarj Noktası
9. İBB Avrupa Yakası Şişli/Maçka Evlendirme Dairesi Şarj Noktası
10. İstanbul Asf Otomotiv Şarj Noktası
11. İstanbul Bika Renault Esenyurt Plaza Şarj Noktası
12. İstanbul Bika Renault Büyükçekmece Plaza Şarj Noktası
13. İstanbul Renault Boğaziçi Şubesi Şarj Noktası

4.7 Candidate Charge Station Locations

4.7.1 Charging Station Location Considerations

Each city has its own characteristic. There are many amount of research in the past, but they are still insufficient to adapt to any another city or another culture. Each of them addresses a proper solution to a specific case except a little amount of research. Generalizing model makes the solution less successful and make away from optimal solution. The location of EV charging stations involve several considerations.

Parking spaces in a station must be designed properly to use the station area efficiently. Moreover, infrastructure for providing electricity should be enough for the demand. Charger next to a parking space in close enough proximity that the connecting cable allows the connector to be able to reach the electric vehicle's charging receptacle when the vehicle is parked properly.

	Charger Types		
Places	Level 1	Level 2	Level 3
Houses	√	√	-
Offices and Business Centers	√	√	-
Public Places (hotels, airports, hospitals ,shopping centers etc.)	√	√	√
University	√	√	-
Gas Stations	-	√	√
Parking Spaces	√	√	√
Streets	-	√	√
Intercity roads and Highway	-	-	√

Table 4.2: Charger types and usage areas

4.7.1.1 Shopping centers

There are 46 shopping centers in İstanbul currently and they are increasing continuously [76]. They are listed with their places. Their parking garage can be used for charging cars while customers are shopping or spending their time. Also they might park their cars for whole night to charge it with slow charger (8 hours), Otherwise, fast chargers (30-60 min) can be preferred. Open their parking centers to all customers for whole night might be good for electric car owners.

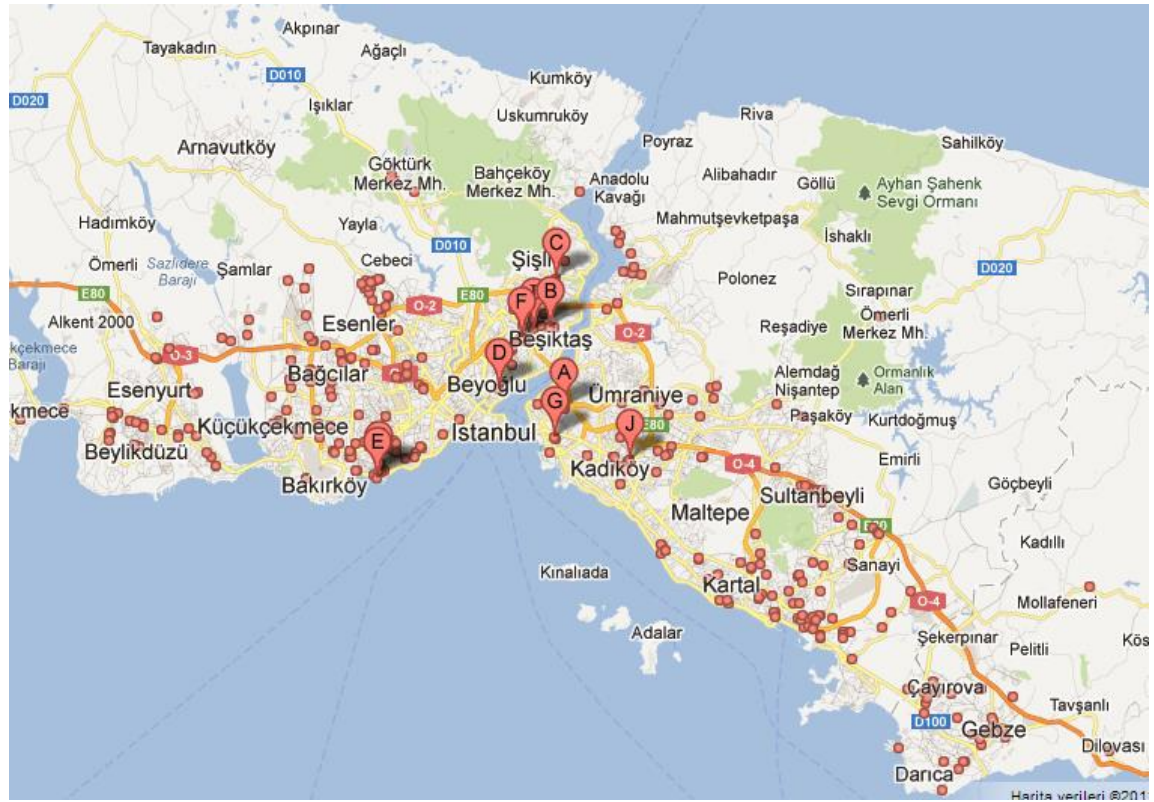


Figure 4.3: Shopping centers in İstanbul

Districts in İstanbul	Potential Places	Distance from Center of District (Km)
Arnavutköy	-	-
Ataşehir	Palladium Shopping Center, Ataşehir	4.1
	Optimum Outlet, Yenisahra, Ataşehir	6
	Novada Ataşehir, Ataşehir	1.8
	Brandium Shopping Center, Ataşehir	1.4
	D&R Trio Hillside City Club	3
Avcılar	Torium, Avcılar	4.8
	Pelican Mall, Avcılar	4.1
Bağcılar	Güneşli Park Shopping Center, Güneşli, Bağcılar	2.4

	212 İstanbul Power Outlet, Bağcılar	1.9
Bahçelievler	Kadir Has Çocuk Dünyası, Bahçelievler	3.7
	Bahçepark CarrefourSA Shopping Center, Bahçelievler	6.7
	Metroport Shopping Center, Bahçelievler	4.7
	StarCity, Yenibosna, Bahçelievler	1.9
	Ömür Plaza, Bahçelievler	7.8
Bakırköy	Airport Outlet Center, Bakırköy	7.4
	Aqua Florya Shopping Mall, Bakırköy	2.4
	Ataköy Plus, Bakırköy	4.7
	Atrium Shopping Center , Bakırköy	5.7
	Carousel Shopping Center, Bakırköy	5.2
	Capacity Shopping Mall, Bakırköy	5.1
	DünyAVM-İstanbul World Trade Center	4.4
	Forum Marmara, Bakırköy	7.9
	Galleria Ataköy, Bakırköy	4.7
	Flyinn, Florya, Bakırköy	2.5
	Town Center, Bakırköy	7.1
Başakşehir	Deposit Outlet Mall, Başakşehir	4.7
	Olimpa, Başakşehir	1.6
	Merkez Kayaşehir, Küçükçekmece	16.7
	Prestige Mall, Başakşehir	17.7
Bayrampaşa	Akvaryum Shopping Mall, Bayrampaşa	2.7
	Forum İstanbul, Bayrampaşa	0.45
	Ora Outlet, Bayrampaşa	7.5
Beşiktaş	Akmerkez, Etiler, Beşiktaş	1.3
	Çarşı-Pazar Levent, Beşiktaş	3.9
	G-Mall, Dolmabahçe, Beşiktaş	6.4
	Kanyon, Levent, Beşiktaş	3.4
	Mayadrom Akatlar, Akatlar, Beşiktaş	2.4
	Mkm Shopping Mall, Beşiktaş	3.5
	Kule Çarşı, Levent, Beşiktaş	2.8
	MetroCity AVM, Levent, Beşiktaş	3.9
	Sapphire Çarşı, Sapphire of İstanbul, Levent, Beşiktaş	2.4

	Zorlu Center, Beşiktaş	3
Beykoz		
Beylikdüzü	Beylicium, Beylikdüzü	3.2
	Beylikdüzü Migros Shopping Center, Beylikdüzü	2.4
	Marmara Park, Beylikdüzü	5.9
	Perla Vista , Beylikdüzü	5.2
	White Corner, Beylikdüzü	2.2
Beyoğlu	Passage Markiz, Beyoğlu	3.1
	Demirören İstiklal, Beyoğlu	2.4
Büyükkçekmece	Atirus Shopping Center, Büyükkçekmece	7.8
	Aymerkez, Mimarsinan, Büyükkçekmece	6.8
Çatalca		
Çekmekoy	Kardiyum, Çekmeköy	15.9
Esenler		
Esenyurt	Akbatı Shopping and Life Center, Esenyurt	4.4
	Eskule, Esenyurt	2.2
	Veneris Shopping Center, Esenyurt	4.6
Eyüp		
Fatih	Historia, Fatih	0.45
Gaziosmpaşa	Viaport Venezia Shopping Mall	4.7
Güngören	Platform Merter - Fashion Park, Merter, Güngören	2.8
	Meydan Shopping Center, Güngören	1.9
	Kale Outlet Center, Güngören	1.2
Kadıköy	Tepe Nautilus, Acıbadem, Kadıköy	7.8
	Kozzy, Kadıköy	1.9
Kağıthane	Axis Mall, Kağıthane	1.2
Kartal	M1 Merkez, Kartal	4
Küçükçekmece	Arena Park Shopping Center, Küçükçekmece	6.1
	ArmoniPark Outlet Center, Küçükçekmece	2.6
Maltepe	Maltepe Park, Maltepe	9.7
	Grandhouse, Maltepe	6.7
Pendik	Viaport, Pendik	10.5
	World Atlantis, Pendik	12.3
	Neomarin, Pendik	21.9

	Pendorya, Pendik	21.5
Sarıyer	Doğuş Center Maslak, Maslak, Sarıyer	11.6
	İstinye Park, İstinye, Sarıyer	13.7
Sancaktepe	Rings İstanbul Shopping Center	9.4
Silivri	Maxi City, Silivri	6.3
Sultanbeyli	Plato Shopping Mall, Sultanbeyli	1.2
Sultangazi	-	
Şile	-	
Şişli	Cevahir Mall, Şişli	11
	City's Nişantaşı, Nişantaşı, Şişli	12.2
	Bomonti Park, Bomonti, Şişli	12.3
	Blackout Şişli, Şişli	12.6
	Profilo Shopping Center, Mecidiyeköy, Şişli	9.5
	Trump Towers Shopping Center, Şişli	10.3
Tuzla		
Ümraniye	Buyaka Shopping Mall, Ümraniye	3.2
	Meydan Shopping Center, Ümraniye	3.2
Üsküdar	Capitol Shopping Center, Üsküdar	2.5
Zeytinburnu	Olivium Outlet Center, Zeytinburnu	1.7

Table 4.3: List of shopping malls in İstanbul and their distances from center of a district

4.7.1.2 Cinema and Theatres

Cinemas and theatres are important candidate places to charge electric vehicles. When people spend their time, their vehicle's batteries are charged. This type of places captures people's attention for several hours. Therefore, drivers do not have to wait just for charging their vehicles.

4.7.1.3 University Campus

Approximately half of the students and most of the university lecturers have cars. Instead of using conventional vehicles, electric vehicles will make their life and living space better and more healthier. Students spend most of their times in campus (from 1 hour to 6 hour approximately). Lecturers spend 8 hours in campus. EV cars can be used in campuses frequently.

Universities	Districts
İstanbul Üniversitesi	Avcılar, Bahçeköy, Bakırköy, Beyazıt,
	Büyüçekmece, Cerrahpaşa, Çapa,
	Horhor, Kadıköy, Laleli, Şişli, Vefa, Vezneciler
Boğaziçi Üniversitesi	Bebek, Beşiktaş
İstanbul Teknik Üniversitesi	Maslak, Maçka, Taşkışla, Gümüşsuyu, Tuzla
Galatasaray Üniversitesi	Ortaköy, Beşiktaş
Marmara Üniversitesi	Göztepe, Haydarpaşa, Bağlarbaşı, Başibüyük, Kartal
	Anadoluhisarı, Acıbadem, Bahçelievler, Nişantaşı
	Sultanahmet, Beyazıt
Mimar Sinan Güzel Sanatlar Üniversitesi	Fındıklı, Beyoğlu
Türk-Alman Üniversitesi	Beykoz
Yıldız Teknik Üniversitesi	Davutpaşa, Beşiktaş, Ayazağa
İstanbul Medeniyet Üniversitesi	
Hava Harp Okulu	Yeşilköy, Bakırköy
Deniz Harp Okulu	Tuzla, İstanbul

Acıbadem Üniversitesi	Maltepe
Bahçeşehir Üniversitesi	Beşiktaş, Mecidiyeköy, Şişli
Beykent Üniversitesi	Büyükcçekmece, Şişli/Ayazağa, Taksim
Bezmiâlem Vakıf Üniversitesi	Fatih
Doğuş Üniversitesi	Acıbadem,Hasanpaşa
Fatih Üniversitesi	Büyükcçekmece,Ostim,Gimat
Fatih Sultan Mehmet Vakıf Üniversitesi	Yenikapı Mevlevihanesi,Fatih,Üsküdar,Çamlıca,Beyoğlu
Gedik Üniversitesi	Pendik
Haliç Üniversitesi	Mecidiyeköy, Fındıkzade, Şişhane, Bomonti
Işık Üniversitesi	Şile, Maslak
İstanbul 29 Mayıs Üniversitesi	Üsküdar
İstanbul Arel Üniversitesi	Sefaköy,Büyükcçekmece
İstanbul Aydın Üniversitesi	Bahçelievler, Florya, Kadıköy, Beşiktaş,
İstanbul Bilgi Üniversitesi	Şişli, Dolapdere, Alibeyköy
İstanbul Bilim Üniversitesi	Esentepe, Gayrettepe, Mecidiyeköy
İstanbul Gelişim Üniversitesi	Avcılar
İstanbul Kemerburgaz Üniversitesi	Mahmutbey, Bağcılar
İstanbul Kültür Üniversitesi	Şirinevler, Ataköy(Yenibosna), İncirli
İstanbul Medipol Üniversitesi	Saraçhane
İstanbul Sabahattin Zaim Üniversitesi	Halkali-Kucukcekmece
İstanbul Şehir Üniversitesi	Üsküdar
İstanbul Ticaret Üniversitesi	Eminönü, Üsküdar, Küçükyalı
Kadir Has Üniversitesi	Cibali, Bahçelievler, Selimpaşa
Koç Üniversitesi	Sarıyer

Maltepe Üniversitesi	Maltepe
Nişantaşı Üniversitesi	Bayrampaşa
Mef Üniversitesi	
Okan Üniversitesi	Hasanpaşa, Tuzla
Özyeğin Üniversitesi	Altunizade, (Alemdağ)
Piri Reis Üniversitesi	Tuzla
Sabancı Üniversitesi	Tuzla
Süleyman Şah Üniversitesi	Kartal
Üsküdar Üniversitesi	Üsküdar
Yeditepe Üniversitesi	Kayışdağı(Ataşehir), Göztepe
Yeni Yüzyıl Üniversitesi	Cevizlibağ, (Topkapı)

Table 4.4: List of universities as a candidate charge stations [77]

4.7.1.4 Business Centers

Working hours generally starts at 8.00 and finished at 6.00. It means that people spend most of their times with working. While they are working, cars can be charged in parking space. It gives you an opportunity to drive between home and work easily.

4.7.1.5 Parking Areas

In İstanbul, parking space is an important problem. They are always full of cars. They can be used as charge stations. Customers put their cars there for a short time (at least for 30 minutes) or long time such as whole night. Amount of total current parking spaces are 528.592 in Istanbul and amount of future parking spaces are 816866 [78].

	Anatolian Side			European Side	Total	
İSPARK	Amount	Car Capacity	Amount	Car Capacity	Amount	Car Capacity
Roadside Park	38	3350	212	12650	250	16000
Parking Garage	6	2150	20	9000	26	11150
Parking Lot	85	11500	150	22500	235	34000
Total	129	17000	382	44150	511	61150

Table 4.5: Type of Parking Garages and their capacities in İstanbul

Private Garages	Number of Garages	Car Capacity
	1680	161000
Others		
Public Buildings	150	11500
Shopping Malls	120	162000
Hospital	50	5000
Private Institutions	1650	96000
Total	3330	435500

Table 4.6: Parking Garages and their capacities in İstanbul

	Number of Garages	Car Capacity
Under Construction	9	2533
Project plans are finished	24	5428
Tender is made	14	5080
Decided by Govenment	36	11870
Phase of Plan	525	246000
Hub Center	79	34482

Table 4.7: Planned Parking Spaces for the Future

4.7.1.6 Gas stations

There are plenty of gas stations all around Turkey. For passengers who travel on a long road can use fast chargers. Also, Hybrid cars both full their gas tank and electric batteries in this kind of places. Amount of chargers can be decided according to how often those stations are used by cars. Charging station which has a proper size can be built inside the gas station therefore it is less costly. Currently, there are approximately 500 gas stations all around in İstanbul [79].

Districts in İstanbul	Number of Gas Stations
Arnavutköy	2
Ataşehir	4
Avcılar	14
Bağcılar	17
Bahçelievler	19
Bakırköy	14
Başakşehir	2
Bayrampaşa	13
Beşiktaş	8
Beykoz	7
Beylikdüzü	2
Beyoğlu	10
Büyükdere	25
Çatalca	10
Çekmeköy	1
Esenler	11
Esenyurt	5
Eyüp	11
Fatih	12
Gaziosmpaşa	11
Güngören	5

Kadıköy	25
Kağıthane	13
Kartal	25
Küçükçekmece	25
Maltepe	6
Pendik	24
Sarıyer	10
Sancaktepe	2
Silivri	25
Sultanbeyli	15
Sultangazi	1
Şile	5
Şişli	25
Tuzla	17
Ümraniye	25
Üsküdar	25
Zeytinburnu	13
TOTAL	484

Table 4.8: List of Gas stations as a candidate charge station

Chapter 5

CHARGING STATION LOCATION DECISION MODELLING

5.1. Main Considerations of Charging Station Modelling

Charging station, which are also called as electric recharging point, charging point or Electric Vehicle Supply Equipment (EVSE), is main consideration when people invest on environmentally friendly vehicles. Locations of them must be easily accessible because of limited ranges of electrical vehicles.

It is necessary to determine charge station location to meet consumer demand while minimizing initial investment. Charging demand is related to the traffic flow of electric vehicles in the city. Number of chargers should meet the demand.

Vehicles must reach the charging stations whenever they need because of their limited ranges. Each charge station should cover an area within range of vehicles. Because of the limited travel range, there is a need of high density of charging stations.

Type of charger should be considered because of their charging duration. When the demand is not so high and time is not important to driver, vehicles can be charged slowly. If time is important or limited, they need to be charged quickly.

Charging environment affects the charging efficiency. When the temperature is normal, batteries charged more efficiently. Otherwise the receptivity of charging reduces. Charging station need to be supplied by the available capacity of power transformers.

While satisfying all conditions above, it is important to minimize total cost of opening charging stations in cheaper places.

5.2. Range of Vehicles

Electrical vehicle range is determined by New European Driving Cycle (NEDC). Each brand may have different kind of range according to engine capacity or type of vehicles. Pure electricity vehicles have very limited ranges which are around 10 kilometres but hybrid vehicle's range can be increased up to 500 kilometres.

Factors which effect the range is [80]:

- Sudden changes in speed increase fuel usage
- Aggressive driving style is a reason of more usage of fuel. Calm and soft usage of vehicles is recommended.
- Inclement on roads effect the fuel usage
- Air Conditioner usage

Economic usage is recommended to increase range of vehicles. Many of the factors for range depend on driver. Knowing ranges of environmental friendly vehicles help to decide distance between two different charging stations. Therefore it is important to analyse current vehicles ranges and use the approximate range of them in location decision.

Vehicle Brand	Range(Just Battery Usage)	Type of Vehicles
Chevrolet Volt	60 km	Hybrid
Toyota Prius	20 km	EV
Renault Fluence	185 km	Hybrid
Renault Kangoo	165 km	EV
Renault Twizy	100 km	EV
Renault Zoé	160 km	EV
Opel Ampera	60 km	Hybrid
Chevrolet Sail	150 km	EV
Citroen C Zero	130 km	EV
Mitsubishi i-Miev	160 km	EV
Nissan Leaf	150 km	EV
Peugeot iOn	150 km	EV
Hyundai I-oniq	120 km	Hybrid
Volvo V60 Plug-in Hybrid	50 km	Hybrid
Volvo C30	150 km	EV
Volvo XC60 Plug in Hybrid Concept	50 km	Hybrid
Volvo V70 Plug in Hybrid	48 km	Hybrid
Audi A1	50 km	EV
Ford Escape Plug-in Vehicle	48 km	Hybrid
Mitsubishi PX-MiEV	48 km	Hybrid
BMW ActiveHybrid	160 km-240km	Hybrid
BMW i3	150 km	EV
BMW i8	35 km	EV
MINI E	160km	EV
Smart ED	112 km	EV
Subaru R1E	80 km	EV
Toyota FT-EV	80 km	EV
Tesla Model S	160 km	EV
Coda Electric sedan	192 km	EV
BMW Megacity	160 km	EV
Ford Focus Electric	122 km	EV

Table 5.1: Ranges of Environmental Friendly Vehicles

5.3. Charging Demand

Charging demand is one of the key issues while deciding the charge station locations. Demand can be predicted in several ways. Traffic density of the road or amount of vehicles in a district can be used as a demand factor.

There is not accurate information about electric vehicles in Istanbul. We have traffic density on some roads and approximate number of vehicles in each 38 district in Istanbul. This information is just for conventional vehicles. Electric vehicle demand can be predicted by multiplying these data with an acceptance rate of electric vehicles.

5.4. Traffic Density

Istanbul consists of three parts, two in Europe and one across the entrance to the Bosphorus in Asia. The two European parts are separated by a stretch of water called The Golden Horn.

Traffic in Istanbul change according to the time and day. Yandex traffic reports and maps show that traffic jam mostly occurs in Kadıköy, Maltepe, Üsküdar, Beykoz, and Beşiktaş. Areas near by the Bosphorus and FSM bridges are mostly crowded. Speed of vehicles change from 15 km to 30 km in this area. Traffic jam on bridges and around of it, starts at 7am and continue until midnight every day. Especially weekends of it starts at 7am and continue until 2pm. Traffic of other regions are generally crowded between 7 am and 10 am the in the evening hours from 3 pm to 11 pm. Speed of vehicles change from 15 to 40 km. Yandex show the traffic information with different colours and 3 groups. Red colour represents the most crowded traffic, drivers waits for a long time, yellow one represents that traffic stops in some point and continue, green colour represents that traffic

is open [86]. Istanbul residents faced traffic chaos every day. According to the reports, traffic was almost stopped in some locations.

Daily Traffic density in İstanbul according to the hours:

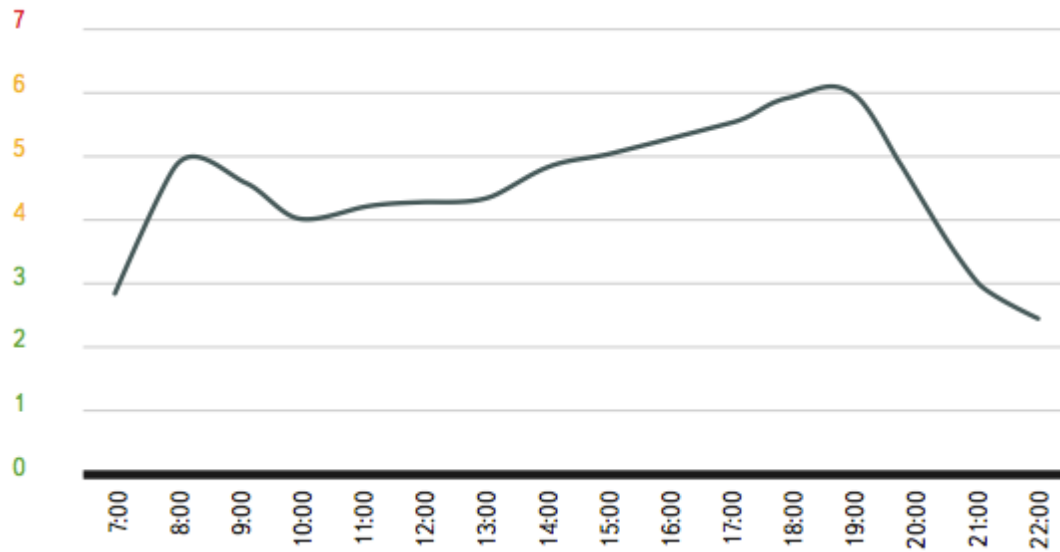


Figure 5.1 Traffic density in a day [81]

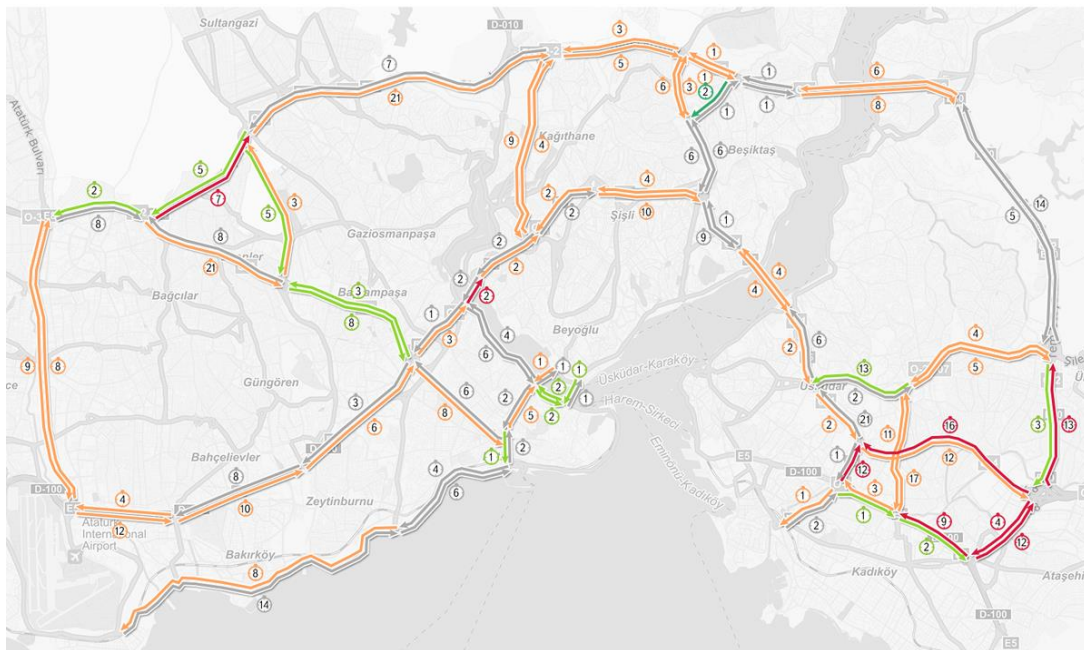


Figure 5.2: Map which shows traffic density with colours [81]

Weekly Traffic density in İstanbul Scala from 1 to 7 for traffic density is:

1. Roads are free
2. Roads are almost free
3. Traffic is cramped in some places
4. Traffic is cramped in some places
5. Traffic is congested
6. Traffic is congested
7. Traffic is quite cramped
8. Traffic is crawling
9. Traffic stopped
10. Advise you to use subway.

2010, 2011 and 2012 Annual Average Daily Traffic Values is used for creating the table 5.3 [82], 5.4 [83] and 5.5 [84]. Annual Average Daily Traffic Values (AADT) values on state roads are determined by four different automatic counting devices. Devices are different from each other because of different working principles therefore their accuracy level is different. Generally, accuracy rate is approximately %95 on traffic counts and %90 on classification counts [84]. Traffic data are presented according to control sections number on the state roads for all road segments.

Region (2010)	Kkno	Part No	Lenght (Km)	Annual Average Daily Traffic (Aadt)	Annual Average Daily Traffic Of Personal Vehicles	Percentage of Personal Vehicles
Istanbul	100-04	1	11	11739	8460	72,06
Istanbul	100-04	2	12	20806	16621	79,88
Istanbul	100-04	3	11	26097	21650	82,95
Istanbul	100-04	4	8	24634	19964	81,04
Istanbul	100-04	5	10	30885	25725	83,29
Istanbul	110-05	0	9	13623	10818	79,40
Istanbul	567-02	1	8	9107	6178	67,83
Istanbul	567-02	2	15	1832	1387	75,70
Istanbul	569-01	1	10	6404	5175	80,80
Istanbul	569-01	2	7	14603	10809	74,01
Istanbul	569-01	3	10	11901	8666	72,81
Istanbul	020-05	1	18	1080	731	67,68
Istanbul	020-05	2	26	2949	2325	78,84
Istanbul	020-06	1	26	770	439	57,01
Istanbul	020-06	2	23	4741	1083	22,84
Istanbul	020-06	3	9	37456	28305	75,56
Istanbul	020-07	1	19	5488	3708	67,56
Istanbul	020-07	2	9	16903	11749	69,50
Istanbul	020-07	3	16	7976	6448	80,84
Istanbul	020-07	4	14	7976	6948	87,11
Istanbul	020-08	1	19	933	777	83,27
Total			290	257903	197966	76,75

Table 5.2: Traffic density of main roads of İstanbul in 2010

Region (2011)	KKNO	Part No	Lenght (Km)	Annual Average Daily Traffic Of Personal Vehicles	Annual Average Daily Traffic (Aadt)	Percentage Of Personal Vehicles
Istanbul	016-02	0	12	13179	17693	74,49
Istanbul	100-04	1	11	10321	14111	73,14
Istanbul	100-04	2	12	16786	20853	80,50
Istanbul	100-04	3	11	23782	28776	82,65
Istanbul	100-04	4	8	19386	24037	80,65
Istanbul	100-04	5	10	26806	31792	84,32
Istanbul	110-05	0	9	11250	14211	79,16
Istanbul	567-02	1	8	6985	10391	67,22
Istanbul	567-02	2	15	1610	2126	75,73
Istanbul	569-01	1	10	5123	6492	78,91
Istanbul	569-01	2	7	10665	14996	71,12
Istanbul	569-01	3	10	8579	12294	69,78
Istanbul	020-05	1	18	703	1016	69,19
Istanbul	020-05	2	26	2204	2682	82,18
Istanbul	020-06	1	26	417	686	60,79
Istanbul	020-06	2	23	1591	6742	23,60
Istanbul	020-06	3	9	31924	42511	75,10
Istanbul	020-07	1	19	3411	5339	63,89
Istanbul	020-07	2	9	10762	16456	65,40
Istanbul	020-07	3	16	5331	7457	71,49
Istanbul	020-07	4	14	5951	6879	86,51
Istanbul	020-08	1	19	1926	2360	81,61
Istanbul	020-08	1	28	564	710	79,44
Total			330	219256	290610	

Table 5.3: Traffic density of main roads of İstanbul in 2011

Region (2012)	KKNO	Part No	Lenght (Km)	Annual Average Daily Traffic Of Personal Vehicles	Annual Average Daily Traffic (Aadt)	Percentage Of Personal Vehicles
İstanbul	34-02		22	-	-	-
İstanbul	34-06	0	23	2958	4086	72.39
İstanbul	34-07	0	2	152	177	85.87
İstanbul	34-08	0	2	4332	4899	88.42
İstanbul	34-11	0	5	88787	94474	93.98
İstanbul	34-12	0	4	51877	55204	93.97
İstanbul	34-13	0	3	67351	129161	52.14
İstanbul	34-25	0	8	404	6335	6.37
İstanbul	34-27	0	10	1491	22663	6.57
İstanbul	34-28	0	10	12239	18478	66.23
İstanbul	34-81	1	22	2663	3513	75.80
İstanbul	34-81	2	13	428	602	71.09
İstanbul	34-84	0	9	29101	38234	76.11
İstanbul	34-85	0	4	41269	57051	72.33
İstanbul	34-86	0	3	7065	19147	36.89
İstanbul	34-89	0	3	21286	28517	74.64
İstanbul	34-90	0	36	-	-	-
Total			179	331403	482541	

Table 5.4: Traffic density of main roads of İstanbul in 2012

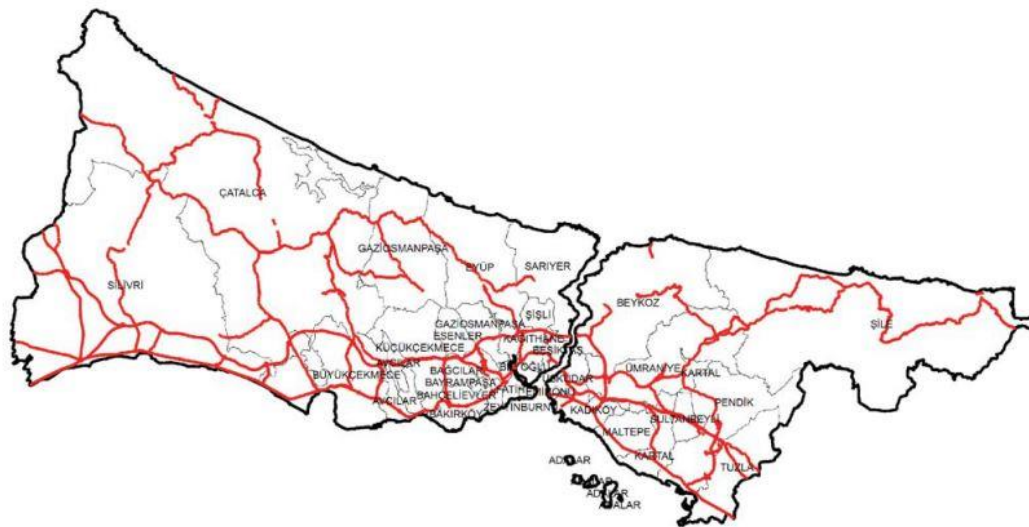
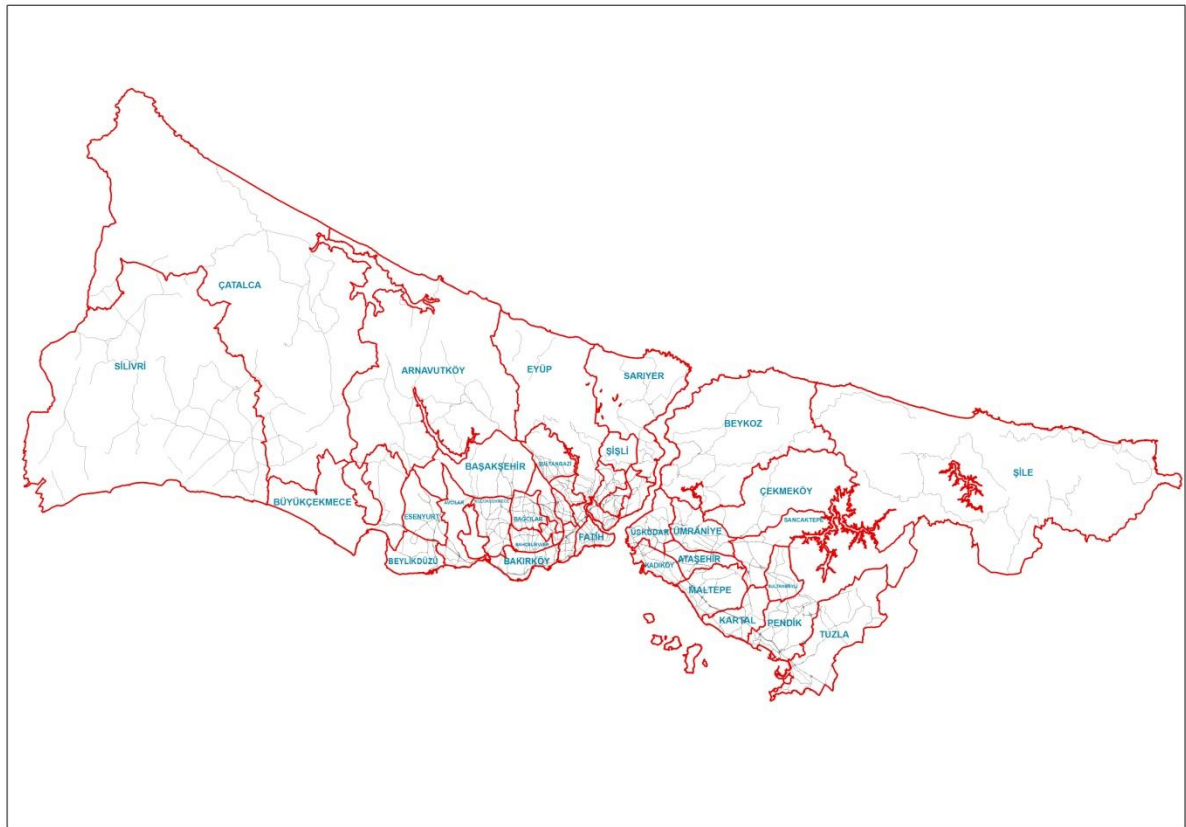


Figure 5.3 Main roads and districts of İstanbul

5.5. Location of Planned Charge Stations

Istanbul has very busy roadways. Distances between center of two districts are generally far from each other and each of them has different amount of traffic density. Variety of these traffic densities is mainly because of the position and population of the district.



There are 38 districts in İstanbul

- | | |
|-----|--------------|
| D.1 | Arnavutköy |
| D.2 | Ataşehir |
| D.3 | Avcılar |
| D.4 | Bağcılar |
| D.5 | Bahçelievler |
| D.6 | Bakırköy |
| D.7 | Başakşehir |

D.8	Bayrampaşa
D.9	Beşiktaş
D.10	Beykoz
D.11	Beylikdüzü
D.12	Beyoğlu
D.13	Büyükdere
D.14	Çatalca
D.15	Çekmeköy
D.16	Esenler
D.17	Esenyurt
D.18	Eyüp
D.19	Fatih
D.20	Gaziosmanpaşa
D.21	Güngören
D.22	Kadıköy
D.23	Kağıthane
D.24	Kartal
D.25	Küçükçekmece
D.26	Maltepe
D.27	Pendik
D.28	Sarıyer
D.29	Sancaktepe
D.30	Silivri
D.31	Sultanbeyli

- D.32 Sultangazi
- D.33 Şile
- D.34 Şişli
- D.35 Tuzla
- D.36 Ümraniye
- D.37 Üsküdar
- D.38 Zeytinburnu

5.5.1. Cost of Different Districts in İstanbul

Districts in İstanbul have different land cost. Therefore, opening them in different districts have different initial cost. Cost for opening a charge station change by district to district according to square meter prices basically

	Square Meter Cost				Square Meter Cost		
Districts	Least	Most	Average	Districts	Least	Most	Average
Arnavutköy	20	700	360	Gaziosmanpaşa	151	1130	640.5
Ataşehir	70	5000	2535	Güngören	500	3000	1750
Avcılar	60	900	480	Kadıköy	250	5000	2625
Bağcılar	360	1600	980	Kağıthane	80	2500	1290
Bahçelievler	300	2500	1400	Kartal	130	2100	1115
Bakırköy	350	2100	1225	Küçükçekmece	310	2070	1190
Başakşehir	150	2500	1325	Maltepe	210	2000	1105
Bayrampaşa	500	1000	750	Pendik	250	800	525
Beşiktaş	300	4700	2500	Sancaktepe	15	200	107.5
Beykoz	8	1000	504	Sarıyer	80	1300	690
Beylikdüzü	500	500	500	Silivri	1	500	250.5
Beyoğlu	10000	24000	17000	Sultanbeyli	40	200	120
Büyükçekmece	10	350	180	Sultangazi	80	300	190
Çatalca	2	330	166	Şile	3	100	51.5
Çekmeköy	40	500	270	Şişli	4900	10400	7650
Esenler	450	1000	725	Tuzla	50	200	125
Esenyurt	100	1000	550	Ümraniye	35	800	417.5
Eyüp	100	1550	825	Üsküdar	500	3000	1750
Fatih	5200	12000	8600	Zeytinburnu	500	7500	4000

Table 5.5: Square meter costs of districts in İstanbul [88]

5.5.2. Origin-Destination Matrix

Minimum distances between districts in İstanbul are shown in the tables below [85].

	D.1	D.2	D.3	D.4	D.5	D.6	D.7	D.8	D.9	D.10	D.11	D.12	D.13
D.1	6	58	39	30	35	41	33	26	45	54	40	40	40
D.2	57	10	53	42	47	43	45	31	23	28	61	27	72
D.3	55	52	23	22	17	16	28	28	37	60	10	32	21
D.4	24	39	24	7	8	13	10	13	25	38	25	20	36
D.5	40	39	29	9	8	8	14	20	25	45	30	20	41
D.6	45	40	17	14	9	10	20	17	25	50	21	20	31
D.7	28	43	27	8	13	19	27	16	28	42	28	23	38
D.8	31	30	29	16	20	18	19	7	16	34	35	11	45
D.9	42	20	37	27	31	27	30	16	6	24	46	11	56
D.10	51	25	58	40	45	50	43	36	20	21	59	30	69
D.11	55	62	13	28	25	23	30	35	47	61	10	43	15
D.12	37	26	33	22	27	18	26	12	11	31	41	6	52
D.13	40	69	20	35	32	31	37	43	55	68	16	50	18
D.14	46	76	37	42	46	52	44	49	61	74	38	56	18
D.15	56	8	56	45	49	55	48	34	26	27	64	29	74
D.16	23	36	28	10	15	21	13	6	22	34	29	17	39
D.17	48	54	8	20	25	22	22	28	40	53	11	35	16
D.18	32	26	28	17	22	17	20	6	12	30	36	7	46
D.19	32	29	28	17	21	15	20	6	15	33	32	5	42
D.20	23	34	30	12	17	23	16	5	18	30	31	13	42
D.21	31	33	34	16	6	12	19	7	19	41	35	14	45
D.22	52	9	48	37	42	38	41	27	18	26	56	22	67
D.23	36	22	34	23	28	23	26	12	8	22	42	6	52
D.24	71	20	68	57	62	58	60	46	38	42	76	41	86
D.25	28	46	14	9	6	10	13	20	32	45	18	27	29
D.26	61	12	57	46	51	47	50	36	27	35	65	31	76
D.27	73	31	79	62	67	69	65	57	49	45	81	52	91
D.28	47	35	53	35	40	46	39	31	19	34	54	26	65
D.29	67	26	66	55	60	66	58	44	36	38	74	40	84
D.30	64	92	54	58	63	69	60	66	78	91	40	73	27
D.31	66	15	63	52	57	52	55	41	33	37	71	36	81
D.32	20	37	34	16	21	27	19	12	27	33	35	19	46
D.33	104	63	103	92	97	103	95	81	73	58	111	77	122
D.34	37	26	44	26	31	37	29	22	9	24	45	16	55
D.35	78	27	75	64	69	65	67	53	45	49	83	48	93
D.36	49	10	47	37	42	36	40	25	17	20	56	20	67
D.37	46	13	42	31	36	32	34	20	12	25	50	16	61
D.38	33	36	25	21	16	9	26	10	22	40	29	13	39

Table 5.6: Origin distance matrix from district 1 to 13

	D.14	D.15	D.16	D.17	D.18	D.19	D.20	D.21	D.22	D.23	D.24	D.25	D.26
D.1	45	58	24	30	31	32	23	31	58	35	74	29	66
D.2	77	8	37	57	28	31	35	38	5	24	20	48	12
D.3	39	54	29	9	27	28	37	22	48	33	67	12	57
D.4	41	42	5	21	15	15	14	8	36	20	55	9	44
D.5	46	42	14	26	15	15	22	6	36	21	55	10	44
D.6	51	42	19	31	15	16	27	10	36	21	55	9	45
D.7	44	45	10	23	18	19	18	18	39	24	58	14	48
D.8	50	32	7	30	6	6	6	6	27	11	46	22	35
D.9	62	23	22	41	12	15	23	23	17	8	36	33	25
D.10	75	25	34	54	31	33	30	41	25	31	41	46	34
D.11	39	65	29	7	37	38	38	29	58	43	77	19	67
D.12	57	28	18	37	8	5	17	18	22	7	41	28	31
D.13	18	72	37	15	45	45	45	26	66	51	85	27	74
D.14	5	78	43	30	51	52	51	51	72	57	91	18	81
D.15	80	29	39	59	30	33	35	41	15	26	22	51	24
D.16	45	38	12	24	12	12	8	11	33	17	52	16	41
D.17	32	57	22	11	30	30	30	30	51	36	70	18	59
D.18	52	29	12	31	28	5	13	13	23	8	42	23	31
D.19	52	31	12	31	4	7	9	9	26	10	45	23	34
D.20	47	34	7	27	8	11	5	10	34	14	50	18	37
D.21	51	36	11	30	9	9	12	4	30	15	49	12	38
D.22	72	16	33	52	23	26	34	33	12	19	16	43	11
D.23	58	25	18	37	9	11	13	19	19	6	38	29	27
D.24	92	32	52	71	43	46	50	53	24	39	19	63	16
D.25	46	49	14	18	22	23	22	22	43	28	62	10	52
D.26	81	24	42	61	32	35	43	42	12	28	13	52	11
D.27	97	21	56	76	53	56	52	64	35	50	35	68	21
D.28	70	38	30	50	27	30	26	36	32	20	51	41	40
D.29	90	15	49	70	41	44	46	51	26	37	21	61	16
D.30	34	95	60	39	68	68	68	68	89	74	108	62	97
D.31	87	27	47	66	37	40	45	48	19	33	19	58	12
D.32	51	36	11	31	17	18	7	17	37	15	52	22	45
D.33	127	52	87	107	78	81	83	88	63	74	62	98	72
D.34	61	28	20	40	17	20	16	27	22	8	41	32	31
D.35	99	39	59	78	49	52	57	60	31	46	22	70	32
D.36	72	9	32	52	21	24	28	32	10	17	26	43	18
D.37	66	14	26	46	17	20	27	27	10	13	29	37	18
D.38	53	39	13	33	11	10	14	5	33	18	52	17	41

Table 5.7: Origin distance matrix from district 14 to 26

	D.27	D.28	D.29	D.30	D.31	D.32	D.33	D.34	D.35	D.36	D.37	D.38
D.1	85	41	70	60	69	20	107	38	80	53	50	34
D.2	31	37	20	94	15	39	57	27	26	11	14	35
D.3	78	52	66	44	63	41	103	42	74	46	42	25
D.4	66	34	54	58	50	13	91	23	61	33	29	20
D.5	66	39	54	63	50	26	91	30	61	33	29	12
D.6	66	40	54	68	51	31	91	30	62	34	30	9
D.7	69	37	57	60	54	16	94	26	65	37	33	26
D.8	57	30	44	67	41	17	82	21	52	24	20	10
D.9	47	22	35	78	31	28	72	12	43	15	11	19
D.10	52	34	38	91	37	34	58	25	48	20	25	37
D.11	89	57	77	39	73	42	114	45	84	56	52	32
D.12	53	26	40	74	37	21	77	16	48	20	16	15
D.13	96	64	84	27	80	80	121	53	92	64	59	39
D.14	102	70	90	34	86	55	127	59	98	70	66	56
D.15	19	39	12	96	18	39	49	30	29	10	15	37
D.16	63	29	50	62	47	10	88	18	58	30	26	16
D.17	81	49	69	48	65	34	106	38	77	49	44	30
D.18	53	26	41	68	37	18	78	17	48	20	16	9
D.19	56	29	43	68	40	18	80	20	51	23	19	9
D.20	61	26	46	64	45	7	83	14	56	29	23	14
D.21	60	33	48	67	44	17	85	24	55	27	23	5
D.22	35	32	28	89	20	38	65	23	31	9	9	30
D.23	49	18	37	74	33	17	74	7	45	17	12	15
D.24	32	52	22	109	21	54	63	42	21	26	29	50
D.25	73	41	61	63	57	26	98	30	69	41	37	18
D.26	20	41	16	98	12	47	56	32	30	18	18	39
D.27	27	57	9	114	14	56	51	47	14	27	32	61
D.28	62	21	50	87	46	30	87	16	58	30	25	34
D.29	9	50	14	107	9	50	44	40	20	20	25	48
D.30	119	87	107	26	103	72	144	76	114	87	82	72
D.31	17	46	10	103	6	49	51	37	12	20	24	44
D.32	64	28	48	68	48	11	86	17	59	31	32	20
D.33	51	87	44	144	51	87	8	77	62	58	62	85
D.34	52	16	40	77	37	20	77	10	48	20	16	25
D.35	14	59	20	116	13	61	62	49	15	32	36	56
D.36	37	32	21	89	21	32	58	22	32	9	5	28
D.37	40	26	26	83	24	33	63	16	36	6	10	24
D.38	63	37	51	70	47	19	88	27	59	31	26	9

Table 5.8: Origin distance matrix from district 27 to 38

There is no official number for registered vehicles in a district, therefore estimated number of vehicles in a district calculated with using population of a district, whole population in İstanbul and number of all registered vehicles in İstanbul.

Districts	Number of Estimated Passenger Vehicles	Districts	Number of Estimated Passenger Vehicles
Arnavutkoy	27787	Gaziosmanpasa	67641
Bagcilar	104659	Kagithane	58854
Basaksehir	39878	Maltepe	63372
Beykoz	34663	Sancaktepe	37502
Buyukcekmece	27032	Sultangazi	41792
Esenler	64673	Tuzla	27646
Fatih	60183	Zeytinburnu	41103
Kadikoy	74571	Avcilar	53789
Kucukcekmece	99678	Bakirkoy	30931
Sariyer	40273	Besiktas	26220
Sultanbeyli	67735	Beyoglu	34792
Sisli	44962	Cekmekoy	25654
Uskudar	74597	Eyup	48470
Atasehir	54317	Gungoren	43332
Bahcelievler	84229	Kartal	61800
Bayrampasa	37806	Pendik	85440
Beylikduzu	30575	Silivri	20295
Catalca	8884	Sile	4044
Esenyurt	70090	Umraniye	88533

Table 5.9: Approximate Number of Vehicles in İstanbul according to districts

5.5.3. Charge Station Model 1

In charge station location model, objective is minimizing the cost of opening charge station. We build a model based on optimizing the number of charge stations, locations and capacity of EV charging stations to minimize the overall investment cost.

Minimum number of sets are selected and selected sets contain all the elements that are contained in any of the sets in the input.

Fixed cost of a station is weight coefficients of the district according to how expensive they are.

Minimum charger amount is 20 per charge station and maximum charger amount is 150 per charge station.

Total number of environmentally friendly vehicles is predicted by number of vehicles per district and rate of environmentally friendly vehicles. Rate of vehicles α is 0.05. Quantity and distribution forecast of them is found according to amount of vehicles in the districts in Istanbul.

Istanbul is large area and it can be divided into small parts to apply model. Number of charger station need and estimated amount of environmentally friendly vehicles are written in the table. GAMS/Cplex solver is used to obtain solutions for proposed formulation.

Indices are:

i : Index representing districts in İstanbul, (1..38)

j : Index representing districts in İstanbul, (1..38)

k: Index representing type of charger,(1,4,8)

Parameters are:

Ck: Cost of charger k

fj : Fixed cost opening station in j

α : Rate of electric vehicle

- r : Range of electric vehicle (10 km)
 d_{ij} : Minimum distances between i and j
 I_j : Population of İstanbul
 P_j : Population of district j
 C_n : Number of vehicles in İstanbul
 S_j : Amount of vehicles that can visit node j

$$S_j = C_n \frac{P_j}{I_j} \quad (5.1)$$

Table 5.10 shows S_j values

- T_k : Charging time per vehicle with using mode k
 $T_1 = 1, T_4 = 4, T_8 = 8$
 T : Total available charging hours in a Charge station (24 hours)
 y_k : Maximum amount of vehicle that can be charged in a day with using mode k

$$y_k = \frac{T}{t_k} \quad (5.2)$$

$$B_{ij} = \begin{cases} 1 & \text{if distance between } i \text{ and } j \text{ is less than range } (d_{ij} < r) \\ 0 & \text{Otherwise} \end{cases}$$

$Q_{\max}$: Maximum amount of charger in a station

$Q_{\min}$: Minimum amount of charger in a station

Decision variables are :

X_j : Binary variable, 1 if station in district j is open, 0 otherwise

q_{jk} : Number of charger k in station j

n_j : Number of station that should be open in district j

Objective function minimizes the opening cost of a charge station in district j and cost of charger in a station and balance the number of chargers in a station

$$\min \sum_{j=1}^m f_j n_j + h \quad \forall j \quad (5.3)$$

Objective function (5.3) calculate total cost of opening a station in a district j and h help to distribute chargers and prevent model to the assign all charger need to cheapest one. There is a trade off between charger cost and how many vehicles that we can charge in a day. In some situation, it is better to invest on cheapest charger and less customer. On the other hand, in some situation it is better to charge many vehicles in a day.

Constraints are:

$$\sum_{i=1}^m b_{ij} x_j \geq 1 \quad \forall j \quad (5.4)$$

Constraint (5.4) help model to serve all districts in 10 km range. b_{ij} is a 1-0 matrix which is 1 if j covers i , 0 otherwise. x_j is a binary variable.

$$S_j \alpha \leq \sum_k q_{jk} y_k \quad \forall j \quad (5.5)$$

Constraint (5.5) help to find charger type k amount in a district j .

$$\sum_k q_{jk} = Q_j \quad \forall j \quad (5.6)$$

Constraint (5.6) sums all chargers in district j .

$$Q_j \leq Q_{\max} n_j \quad \forall j \quad (5.7)$$

Constraint (5.7) help to find how many charge station need to be opened in district j . There is an upper limit for charger amount in a station. With this constraint, minimum number of n_j is found.

$$Q_j \geq Q_{\min} n_j \quad \forall j \quad (5.8)$$

Constraint (5.8) help to find how many charge station need to be opened in district j . There is an lower limit for charger amount in a station. With this constraint, maximum number of n_j is found.

$$h \geq c_k \sum_j q_{jk} \quad \forall k \quad (5.9)$$

Constraint (5.9) helps to balance different type of chargers in a district j .

$$n_j \geq x_j \quad \forall j \quad (5.10)$$

Constraint (5.10) is necessary to bind n_j and x_j . When x_j is 1 which means we need to open a station in j then n_j must be at least 1 which means there must be at least 1 station.

$$n_j \leq Mx_j \quad \forall j \quad (5.11)$$

Constraint (5.11) is necessary to bind n_j and x_j . M is a big number and limits amount of n_j

Charger types according to districts are written in the table below

Results of the model are:

	Amount of charge stations	Charger Amounts			Amount of Electric Vehicles alfa=0.05
		Fast	Medium	Slow	
Arnavutkoy	3		14	436	1389.35
Atasehir	1	101	49		2715.85
Avcilar	3	12	363	75	2689.45
Bagcilar	12	1		1737	5232.95
Bahcelievler	2	134	166		4211.45
Bakirkoy	1	36	114		1546.55
Basaksehir	4		65	535	1993.9
Bayrampasa	4		31	569	1890.3
Besiktas	1	23	126	1	1311
Beykoz	1	47	99	4	1733.15
Beylikduzu	1	35	115		1528.75
Beyoglu	1	47	101	2	1739.6
Buyukcekmece	1	26	119	5	1351.6
Catalca	1			149	444.2
Cekmekoy	3			428	1282.7
Esenler	8			1078	3233.65
Esenyurt	8			1169	3504.5
Eyup	1	92	14	44	2423.5
Fatih	2	122		28	3009.15
Gaziosmpasa	8			1128	3382.05
Gungoren	5			723	2166.6
Kadikoy	2	108	187	5	3728.55
Kagithane	1	114	33	3	2942.7
Kartal	1	122	26	2	3090
Kucukcekmece	11		12	1638	4983.9
Maltepe	7		7	1043	3168.6

Pendik	7		374	676	4272
Sariyer	1	62	88		2013.65
Sancaktepe	4		26	574	1875.1
Silivri	1	7	140	3	1014.75
Sultanbeyli	8			1129	3386.75
Sultangazi	5			697	2089.6
Sile	1			68	202.2
Sisli	1	75	75		2248.1
Tuzla	1	27	122	1	1382.3
Umraniye	2	146	154		4426.65
Uskudar	1	109	186		3729.85
Zeytinburnu	4		86	514	2055.15

Table 5.10: Result of Model 1

5.5.4. Charge Station Model 1 with Different Scenario

This scenario is derived from model 1. We add constraints to calculate electricity need. Objective function is modified to calculate electricity cost in addition to fixed cost of charge station and charger cost. Objective function, additional parameters and variables are listed below.

Additional parameters are;

$E_{consumption}$: Energy consumption of a vehicle (kw/km)

Cost : Electricity cost per kW

Additional variables are;

E_j : Total energy need for each district

Objective function minimize the opening cost of a charge station in district j, cost of charger in a station and cost of electricity need in a district

$$\min \sum_{j=1}^m f_j n_j + h + \sum_{j=1} E_j \cos t \quad (5.12)$$

Objective function (5.12) calculate total cost of opening a station in a district j and h help to balance chargers and prevent model to the assign all charger need to cheapest one as the previous model. Additionally, in this model total electricity cost and total amount of electricity need is calculated. All constraints in previous model is used.

$$E_j = \left(\sum_i d_{ij} S_j \alpha \right) E_{consumption} \quad \forall j \quad (5.13)$$

Constraint (5.13) is added to the previous model to find the electricity infrastructure need in a district j. d_{ij} is km between district i and j. S_j multiply by α give amount of expected electric vehicle. $E_{consumption}$ is consumption of electricity (kW) per vehicle per km. Therefore E_j gives the all electricity need in district j in kW unit. GAMS/Cplex solver is used to obtain solutions.

We use different scenarios to determine number of charge stations and chargers. In this case, α values are changed and different solutions are obtained. α values changed between 0.01 and 0.08. Also, electricity consumption is calculated.

Result of scenario:

We use different scenarios to determine number of charge stations and chargers. In this case, α values are changed and different solutions are obtained. α values changed between 0.01 and 0.08. Also, electricity consumption is calculated.

Districts	Number of charge stations	Charger Amounts			Number of Electric Vehicles	Electricity need (kw)
		Fast	Medium	Slow		
					alfa=0.01	
Arnavutkoy	1	11	2	1	277.87	86528.718
Atasehir	1	22	3		543.17	133456.869
Avcilar	1	22	2		537.89	149006.288
Bagcilar	1	30		109	1046.59	214571.882
Bahcelievler	1		140	1	842.29	187089.455
Bakirkoy	1	13			309.31	70262.86
Basaksehir	1	16	2	1	398.78	92740.277
Bayrampasa	1	11	2	35	378.06	72133.848
Besiktas	1			88	262.2	53142.696
Beykoz	1			116	346.63	96460.196
Beylikduzu	1			102	305.75	96421.32
Beyoglu	1			116	347.92	69013.411
Buyukcekmece	1			91	270.32	96293.39
Catalca	1			30	88.84	35692.358
Cekmekoy	1			86	256.54	66864.586
Esenler	1	10		136	646.73	129333.065
Esenyurt	1	12		138	700.9	195298.776
Eyup	1	2		146	484.7	90735.84
Fatih	1		100	1	601.83	113095.894
Gaziosmanpasa	1	11		138	676.41	129546.043
Gungoren	1			145	433.32	86265.346
Kadikoy	1	15		129	745.71	172080.04
Kagithane	1	7		141	588.54	110280.625

Kartal	1	8		142	618	205349.04
Kucukcekmece	1	7	138	1	996.78	237193.769
Maltepe	1	9		140	633.72	170762.191
Pendik	1	20		125	854.4	309737.088
Sariyer	1			135	402.73	113159.075
Sancaktepe	1			126	375.02	115903.681
Silivri	1			68	202.95	104259.474
Sultanbeyli	1		113		677.35	197027.568
Sultangazi	1			140	417.92	91549.555
Sile	1			14	40.44	22325.306
Sisli	1		75		449.62	97279.783
Tuzla	1	11	2	1	276.46	101665.4
Umraniye	1	21		128	885.33	196968.218
Uskudar	1	15		129	745.97	155087.163
Zeytinburnu	1	17	1		411.03	87672.699

Table 5.11: Result of model with alfa=0.01

Districts	Number of charge stations	Charger Amounts			Number of Electric Vehicles alfa=0.02	Electricity need (kw)
		Fast	Medium	Slow		
Arnavutkoy	1		36	114	555.74	173057.436
Atasehir	1	30	3	117	1086.34	266913.738
Avcilar	1	29	6	115	1075.78	298012.576
Bagcilar	5			698	2093.18	429143.764
Bahcelievler	1	58	6	86	1684.58	374178.91
Bakirkoy	1	8	1	141	618.62	140525.719
Basaksehir	1		116	34	797.56	185480.554
Bayrampasa	2			253	756.12	144267.696
Besiktas	1		25	125	524.4	106285.392
Beykoz	1		82	68	693.26	192920.393
Beylikduzu	1	7	5	138	611.5	192842.64

Beyoglu	1		82	68	695.84	138026.822
Buyukcekmece	1		31	119	540.64	192586.781
Catalca	1			60	177.68	71384.717
Cekmekoy	1	3	1	146	513.08	133729.171
Esenler	3			432	1293.46	258666.131
Esenyurt	3	5		428	1401.8	390597.552
Eyup	1	24	6	120	969.4	181471.68
Fatih	1	36		114	1203.66	226191.787
Gaziosmanpasa	3		1	449	1352.82	259092.086
Gungoren	2			289	866.64	172530.691
Kadikoy	1	49	5	96	1491.42	344160.079
Kagithane	1	16	131	3	1177.08	220561.25
Kartal	1	37	3	110	1236	410698.08
Kucukcekmece	1	61	88	1	1993.56	474387.538
Maltepe	1	39		111	1267.44	341524.382
Pendik	1	60		90	1708.8	619474.176
Sariyer	1	17		133	805.46	226318.151
Sancaktepe	2			251	750.04	231807.362
Silivri	1			136	405.9	208518.948
Sultanbeyli	3		2	448	1354.7	394055.136
Sultangazi	1		129	21	835.84	183099.11
Sile	1			27	80.88	44650.613
Sisli	1	13	59	78	899.24	194559.566
Tuzla	1	5		145	552.92	203330.801
Umraniye	1	49	98	3	1770.66	393936.437
Uskudar	1	33	117		1491.94	310174.326
Zeytinburnu	1		125	25	822.06	175345.398

Table 5.12: Result of model with alfa=0.02

Districts	Number of charge stations	Charger Amounts			Number of Electric Vehicles	Electricity need (kw)
		Fast	Medium	Slow		
					alfa=0.03	
Arnavutkoy	2			278	833.61	259586.154
Atasehir	1	50	44	56	1629.51	400370.607
Avcilar	1	40	108	2	1613.67	447018.863
Bagcilar	7			1047	3139.77	643715.645
Bahcelievler	1	91	56	3	2526.87	561268.364
Bakirkoy	1	3	140	7	927.93	210788.579
Basaksehir	3			399	1196.34	278220.83
Bayrampasa	3			379	1134.18	216401.544
Besiktas	1		113	37	786.6	159428.088
Beykoz	1	28	1	121	1039.89	289380.589
Beylikduzu	1	22	2	126	917.25	289263.96
Beyoglu	1	8	142		1043.76	207040.234
Buyukcekmece	1		121	29	810.96	288880.171
Catalca	1			89	266.52	107077.075
Cekmekoy	2			257	769.62	200593.757
Esenler	5			647	1940.19	387999.196
Esenyurt	5			701	2102.7	585896.328
Eyup	1	46	13	91	1454.1	272207.52
Fatih	1	64	4	82	1805.49	339287.681
Gaziosmanpasa	5			677	2029.23	388638.13
Gungoren	3			434	1299.96	258796.037
Kadikoy	1	75	71	4	2237.13	516240.119
Kagithane	1	49	96	5	1765.62	330841.876
Kartal	1	53	97		1854	616047.12
Kucukcekmece	6		109	779	2990.34	711581.306
Maltepe	4		34	566	1901.16	512286.574
Pendik	1	99	12	39	2563.2	929211.264
Sariyer	1	18	127	5	1208.19	339477.226
Sancaktepe	2		76	224	1125.06	347711.044
Silivri	1	7	4	139	608.85	312778.422

Sultanbeyli	5			678	2032.05	591082.704
Sultangazi	3			418	1253.76	274648.666
Sile	1			41	121.32	66975.919
Sisli	1	25	125		1348.86	291839.35
Tuzla	1		127	23	829.38	304996.201
Umraniye	1	105	1	44	2655.99	590904.655
Uskudar	1	85	1	64	2237.91	465261.489
Zeytinburnu	2		112	188	1233.09	263018.097

Table 5.13:Result of model with alfa=0.03

Districts	Number of charge stations	Charger Amounts			Number of Electric Vehicles	Electricity need (kw)
		Fast	Medium	Slow		
Arnavutkoy	3			371	1111.48	346114.872
Atasehir	1	71	78	1	2172.68	533827.476
Avcilar	3		268	182	2151.56	596025.151
Bagcilar	9	7		1340	4186.36	858287.527
Bahcelievler	1	138	8	4	3369.16	748357.819
Bakirkoy	1	34	25	91	1237.24	281051.438
Basaksehir	3		82	368	1595.12	370961.107
Bayrampasa	4			505	1512.24	288535.392
Besiktas	1	9	137	4	1048.8	212570.784
Beykoz	1	28	117	5	1386.52	385840.786
Beylikduzu	1	18	132		1223	385685.28
Beyoglu	1	28	118	4	1391.68	276053.645
Buyukcekmece	1	11	134	5	1081.28	385173.562
Catalca	1			119	355.36	142769.434
Cekmekoy	2		43	257	1026.16	267458.342
Esenler	6			863	2586.92	517332.262
Esenyurt	6		35	865	2803.6	781195.104
Eyup	1	58	91	1	1938.8	362943.36

Fatih	1	93	2	55	2407.32	452383.574
Gaziosmanpasa	6		2	898	2705.64	518184.173
Gungoren	4			578	1733.28	345061.382
Kadikoy	1	116	33	1	2982.84	688320.158
Kagithane	1	81	68	1	2354.16	441122.501
Kartal	1	88	58	4	2472	821396.16
Kucukcekmece	8		130	1070	3987.12	948775.075
Maltepe	5		95	655	2534.88	683048.765
Pendik	8	12	6	1032	3417.6	1238948.35
Sariyer	1	40	107	3	1610.92	452636.302
Sancaktepe	3		51	399	1500.08	463614.725
Silivri	1		121	29	811.8	417037.896
Sultanbeyli	6		4	896	2709.4	788110.272
Sultangazi				558	1671.68	366198.221
Sile	4			54	161.76	89301.226
Sisli	1	50	100		1798.48	389119.133
Tuzla	1	12	135	3	1105.84	406661.602
Umraniye	1	147	2	1	3541.32	787872.874
Uskudar	1	116	33	1	2983.88	620348.652
Zeytinburnu	3		99	351	1644.12	350690.796

Table 5.14: Result of model with alfa=0.04

Districts	Number of charge stations	Charger Amounts			Number of Electric Vehicles	Electricity need (kw)
		Fast	Medium	Slow		
					alfa=0.05	
Arnavutkoy	3	2		448	1389.35	432643.59
Atasehir	1	101	49		2715.85	667284.345
Avcilar	3		447	3	2689.45	745031.439
Bagcilar	12			1745	5232.95	1072859.409
Bahcelievler	2	134	166		4211.45	935447.274

Bakirkoy	1	36	114		1546.55	351314.298
Basaksehir	4		65	535	1993.9	463701.384
Bayrampasa	4		31	569	1890.3	360669.24
Besiktas	1	23	126	1	1311	265713.48
Beykoz	1	47	99	4	1733.15	482300.982
Beylikduzu	1	51	3	96	1528.75	482106.6
Beyoglu	1	47	101	2	1739.6	345067.056
Buyukcekmece	1	26	119	5	1351.6	481466.952
Catalca	1			149	444.2	178461.792
Cekmekoy	3			428	1282.7	334322.928
Esenler	8			1078	3233.65	646665.327
Esenyurt	8			1169	3504.5	976493.88
Eyup	1	85	63	2	2423.5	453679.2
Fatih	1	122		28	3009.15	565479.468
Gaziosmanpasa	8			1128	3382.05	647730.216
Gungoren	5			723	2166.6	431326.728
Kadikoy	2	108	187	5	3728.55	860400.198
Kagithane	1	114	33	3	2942.7	551403.126
Kartal	1	125	5	20	3090	1026745.2
Kucukcekmece	11		12	1638	4983.9	1185968.844
Maltepe	7		7	1043	3168.6	853810.956
Pendik	7		374	676	4272	1548685.44
Sariyer	1	62	88		2013.65	565795.377
Sancaktepe	4		26	574	1875.1	579518.406
Silivri	1	7	140	3	1014.75	521297.37
Sultanbeyli	8			1129	3386.75	985137.84
Sultangazi	5		12	673	2089.6	457747.776
Sile	1			68	202.2	111626.532
Sisli	1	75	75		2248.1	486398.916
Tuzla	1	27	122	1	1382.3	508327.002
Umraniye	2	146	154		4426.65	984841.092
Uskudar	2	108	188	4	3729.85	775435.815
Zeytinburnu	4		86	514	2055.15	438363.495

Table 5.15: Result of model with alfa=0.05

Districts	Number of charge stations	Charger Amounts			Number of Electric Vehicles	Electricity need (kw)
		Fast	Medium	Slow		
					alfa=0.06	
Arnavutkoy	4			556	1667.22	519172.308
Atasehir	1	132	13	5	3259.02	800741.214
Avcilar	3	30	416	4	3227.34	894037.727
Bagcilar	14			2094	6279.54	1287431.291
Bahcelievler	2	181	118	1	5053.74	1122536.729
Bakirkoy	1	54	91	5	1855.86	421577.158
Basaksehir	5		48	702	2392.68	556441.661
Bayrampasa	5		7	743	2268.36	432803.088
Besiktas	1	50	25	75	1573.2	318856.176
Beykoz	1	66	82	2	2079.78	578761.178
Beylikduzu	1	52	98		1834.5	578527.92
Beyoglu	1	66	84		2087.52	414080.467
Buyukcekmece	1	41	104	5	1621.92	577760.342
Catalca	1		28	122	533.04	214154.15
Cekmekoy	3			514	1539.24	401187.514
Esenler	9			1294	3880.38	775998.392
Esenyurt	9			1402	4205.4	1171792.656
Eyup	1	112	36	2	2908.2	544415.04
Fatih	2	101	197	2	3610.98	678575.362
Gaziosmanpasa	9		2	1349	4058.46	777276.259
Gungoren	6			867	2599.92	517592.074
Kadikoy	2	149	149	2	4474.26	1032480.238
Kagithane	1	147		2	3531.24	661683.751
Kartal	4	6	594		3708	1232094.24
Kucukcekmece	13		44	1906	5980.68	1423162.613
Maltepe	8		68	1132	3802.32	1024573.147
Pendik	10		359	991	5126.4	1858422.528
Sariyer	1	85	61	4	2416.38	678954.452
Sancaktepe	5		1	749	2250.12	695422.087
Silivri	1	18	130	2	1217.7	625556.844

Sultanbeyli	9		5	1345	4064.1	1182165.408
Sultangazi	5		86	664	2507.52	549297.331
Sile	1			81	242.64	133951.838
Sisli	1	100	50		2697.72	583678.699
Tuzla	2		253	47	1658.76	609992.402
Umraniye	2	196	99	5	5311.98	1181809.31
Uskudar	2	149	149	2	4475.82	930522.978
Zeytinburnu	5		73	677	2466.18	526036.194

Table 5.16: Result of model with alfa=0.06

Districts	Number of charge stations	Charger Amounts			Number of Electric Vehicles	Electricity need (kw)
		Fast	Medium	Slow		
					alfa=0.07	
Arnavutkoy	5			649	1945.09	605701.026
Atasehir	2	112	185	2	3802.19	934198.083
Avcilar	4	13	576		3765.23	1043044.015
Bagcilar	17			2443	7326.13	1502003.173
Bahcelievler	2	228	70	2	5896.03	1309626.184
Bakirkoy	1	71	75	4	2165.17	491840.017
Basaksehir	6		31	869	2791.46	649181.938
Bayrampasa	6			883	2646.42	504936.936
Besiktas	1	52	98		1835.4	371998.872
Beykoz	1	85	64	1	2426.41	675221.375
Beylikduzu	1	69	81		2140.25	674949.24
Beyoglu	1	86	60	4	2435.44	483093.878
Buyukcekmece	1	56	89	5	1892.24	674053.733
Catalca	1		58	92	621.88	249846.509
Cekmekoy	4			599	1795.78	468052.099
Esenler	10		10	1490	4527.11	905331.458
Esenyurt	11			1636	4906.3	1367091.432
Eyup	1	139	8	3	3392.9	635150.88

Fatih	2	135	160	5	4212.81	791671.255
Gaziosmanpasa	11			1579	4734.87	906822.302
Gungoren	7			1012	3033.24	603857.419
Kadikoy	2	190	110		5219.97	1204560.277
Kagithane	2	129	171		4119.78	771964.376
Kartal	5	4	664	82	4326	1437443.28
Kucukcekmece	15		76	2174	6977.46	1660356.382
Maltepe	10			1479	4436.04	1195335.338
Pendik	10		494	1006	5980.8	2168159.616
Sariyer	1	107	41	2	2819.11	792113.528
Sancaktepe	6			876	2625.14	811325.768
Silivri	1	29	121		1420.65	729816.318
Sultanbeyli	11			1581	4741.45	1379192.976
Sultangazi	6		77	822	2925.44	640846.886
Sile	1			95	283.08	156277.145
Sisli	1	125	25		3147.34	680958.482
Tuzla	2	8	290	2	1935.22	711657.803
Umraniye	3	195	251	4	6197.31	1378777.529
Uskudar	2	191	104	5	5221.79	1085610.141
Zeytinburnu	6		60	840	2877.21	613708.893

Table 5.17: Result of model with alfa=0.07

Districts	Number of charge stations	Charger Amounts			Number of Electric Vehicles	Electricity need (kw)
		Fast	Medium	Slow		
					alfa=0.08	
Arnavutkoy	5			741	2222.96	692229.744
Atasehir	2	142	155	3	4345.36	1067654.952
Avcilar	5		685	65	4303.12	1192050.302
Bagcilar	19			2791	8372.72	1716575.054
Bahcelievler	2	275	22	3	6738.32	1496715.638
Bakirkoy	1	88	59	3	2474.48	562102.877
Basaksehir	7		14	1036	3190.24	741922.214

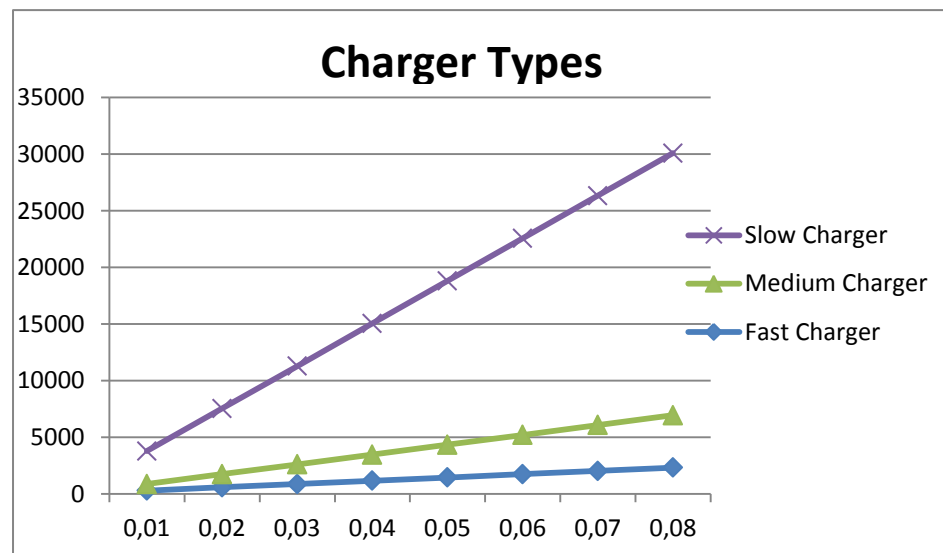
Bayrampasa	7			1009	3024.48	577070.784
Besiktas	1	67	81	2	2097.6	425141.568
Beykoz	1	105	40	5	2773.04	771681.571
Beylikduzu	1	86	64		2446	771370.56
Beyoglu	1	105	43	2	2783.36	552107.29
Buyukcekmece	1	71	74	5	2162.56	770347.123
Catalca	1		87	63	710.72	285538.867
Cekmekoy	4		110	465	2052.32	534916.685
Esenler	12			1725	5173.84	1034664.523
Esenyurt	13			1870	5607.2	1562390.208
Eyup	2	118	167	15	3877.6	725886.72
Fatih	2	168	129	3	4814.64	904767.149
Gaziosmanpasa	12		4	1796	5411.28	1036368.346
Gungoren	8			1156	3466.56	690122.765
Kadikoy	2	232	65	3	5965.68	1376640.317
Kagithane	2	162	136	2	4708.32	882245.002
Kartal	5	25	723	2	4944	1642792.32
Kucukcekmece	17		109	2441	7974.24	1897550.15
Maltepe	11		40	1610	5069.76	1366097.53
Pendik	13		329	1621	6835.2	2477896.704
Sariyer	1	129	21		3221.84	905272.603
Sancaktepe	6		101	799	3000.16	927229.45
Silivri	1	41	105	4	1623.6	834075.792
Sultanbeyli	12		7	1793	5418.8	1576220.544
Sultangazi	7		65	985	3343.36	732396.442
Sile	1			108	323.52	178602.451
Sisli	2	100	199	1	3596.96	778238.266
Tuzla	2	23	277		2211.68	813323.203
Umraniye	5	144	603	3	7082.64	1575745.747
Uskudar	2	232	66	2	5967.76	1240697.304
Zeytinburnu	7		47	1003	3288.24	701381.592

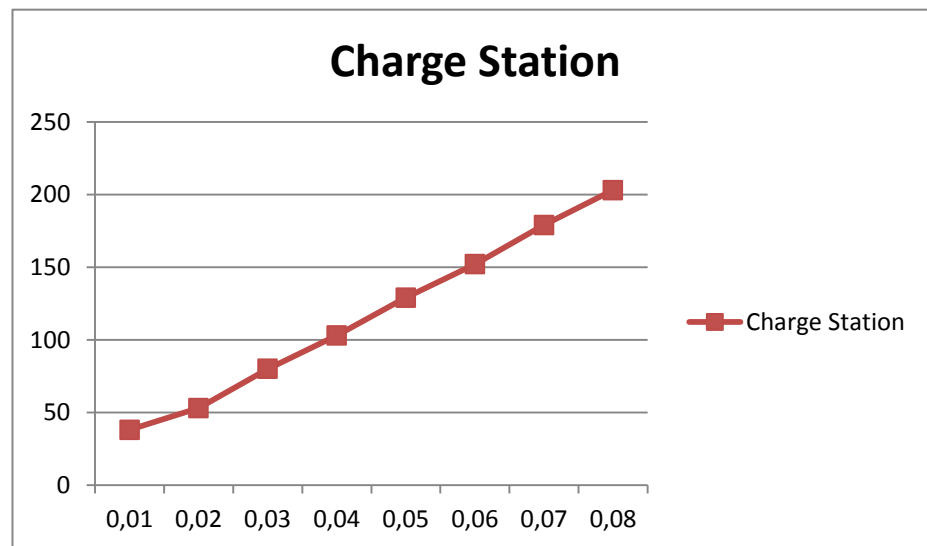
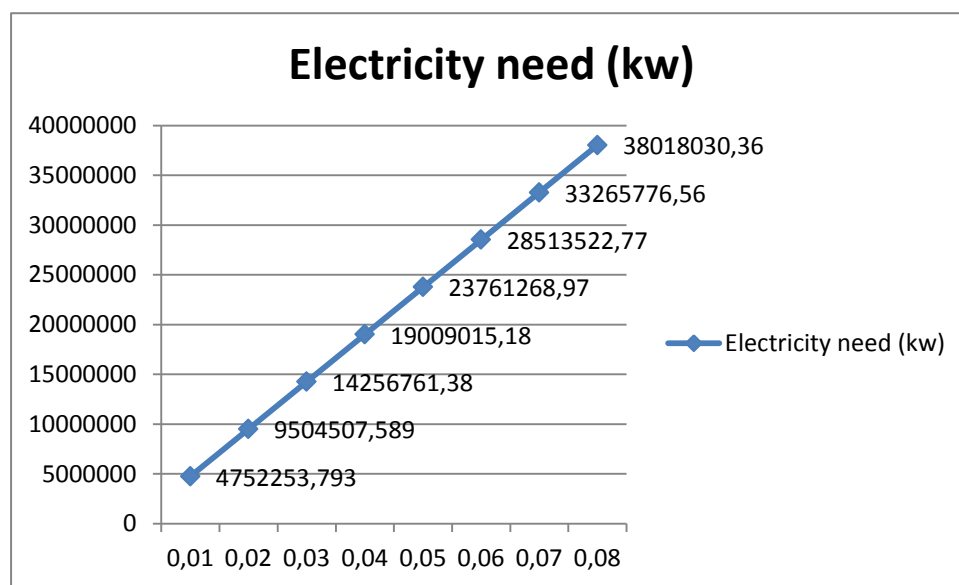
Table 5.18: Result of model with alfa=0.08

Alfa	Charge Station	Fast Charger	Medium Charger	Slow Charger	Amount of EV	Electricity Need	Cost
0.01	38	290	580	2899	19078	4752253.793	7652540.249
0.02	53	579	1158	5792	38156	9504507.589	15297312.59
0.03	80	868	1736	8679	57234	14256761.38	22936891.71
0.04	103	1157	2314	11574	76312	19009015.18	30582302.81
0.05	129	1446	2892	14464	95390	23761268.97	38224843.43
0.06	152	1735	3470	17353	114468	28513522.77	45867037.94
0.07	179	2024	4049	20246	133546	33265776.56	53511907.99
0.08	203	2313	4627	23135	152624	38018030.36	61153776.13

Table 5.19: Summary of results for model 2

Comparison between different α values are shown with figures below.

Figure 5.5: Type of chargers according to different α values

Figure 5.6: Number of charger stations according to different α valuesFigure 5.7: Amount of electricity need according to different α values

5.5.5. Charge Station Model 2

Different than model 1, we assume that each vehicle use 10 meter square place in this case. We use real m^2 prices to analyse how much a station cost considering capacity. In this model, costs are average m^2 cost in a district. GAMS/Cplex solver is used to obtain solutions.

Acceptance rate α is 0.05

Additional Parameter:

$met_j : m^2 \text{ prices}$

Objective function:

$$\min \sum_{j=1}^m f_j n_j + h + \sum_{j=1} E_j \text{ cost } t + \sum_j Q_j met_j \quad (5.14)$$

Objective function (5.14) calculate total cost of opening a station in a district j and h help to distribute chargers and prevent model to the assign all charger need to cheapest one as the previous model and total electricity cost and total amount of electricity need. Additionally, we add another cost which can be called as m2 cost. We assume that each vehicle use 10 m2 place in a station. Each j has different m2 cost. Also each charger can charge only one vehicle in a time. With additional part in objective function, we calculate the total cost of a station according to its size. All constraints in previous model is used.

	Amount of charge stations	Charger Amounts			Amount of Electric Vehicles	Electricity need (kw)
		Fast	Medium	Slow	alfa=0.05	
Arnavutkoy	1	58	0	0	1389.35	432643.6
Atasehir	1	113	1	0	2715.85	667284.3
Avcilar	1	112	1	0	2689.45	745031.4
Bagcilar	2	218	1	0	5232.95	1072859
Bahcelievler	2	176	0	0	4211.45	935447.3
Bakirkoy	1	65	0	0	1546.55	351314.3
Basaksehir	1	83	1	0	1993.9	463701.4
Bayrampasa	1	79	0	0	1890.3	360669.2
Besiktas	1	55	0	0	1311	265713.5
Beykoz	1	72	1	0	1733.15	482301
Beylikduzu	1	64	0	0	1528.75	482106.6
Beyoglu	1	73	0	0	1739.6	345067.1
Buyukc	2	0	226	0	1351.6	481467
Catalca	1	0	75	0	444.2	178461.8
Cekmekoy	2	0	214	0	1282.7	334322.9
Esenler	1	135	0	0	3233.65	646665.3
Esenyurt	1	146	1	0	3504.5	976493.9
Eyup	1	101	0	0	2423.5	453679.2
Fatih	1	126	0	0	3009.15	565479.5
Gaziosmanpasa	1	141	0	0	3382.05	647730.2
Gungoren	1	91	0	0	2166.6	431326.7
Kadikoy	2	156	0	0	3728.55	860400.2
Kagithane	1	123	0	0	2942.7	551403.1
Kartal	1	129	0	0	3090	1026745
Kucukcekmece	2	208	0	0	4983.9	1185969
Maltepe	1	132	1	0	3168.6	853811
Pendik	2	178	0	0	4272	1548685
Sariyer	3	0	336	0	2013.65	565795.4
Sancaktepe	1	78	1	0	1875.1	579518.4
Silivri	2	0	170	0	1014.75	521297.4

Sultanbeyli	4	0	565	0	3386.75	985137.8
Sultangazi	3	0	349	0	2089.6	457747.8
Sile	1	0	34	0	202.2	111626.5
Sisli	1	94	0	0	2248.1	486398.9
Tuzla	2	0	231	0	1382.3	508327
Umraniye	2	184	2	0	4426.65	984841.1
Uskudar	2	156	0	0	3729.85	775435.8
Zeytinburnu	1	86	0	0	2055.15	438363.5
TOTAL	56	3432	2210	0	95390	23761269

Table 5.20: Result of model

5.5.6. Stochastic Optimization

In Stochastic Programming Model, we assume that acceptance rate α is not exogenously given to the decision maker. Rather, we assume that it is a random variable with a known probability distribution.

We use stochastic programming approach to incorporate the randomness of α into the mixed integer linear programming model described before. For now let us assume that α can take N different values from a finite scenario set $\Omega = \{\alpha_1, \alpha_2, \dots, \alpha_N\}$ with an associated probability mass function $P_i = \text{Prob} \{\alpha = \alpha_i\}$, $i=1, \dots, N$.

Since α is random, we assume that the objective is to minimize the total expected cost of opening charging stations.

We add another index set to our formulation. Let

l : index representing the scenario of α , $l = 1, \dots, N$.

Model parameters c_k , f_j , α , S_j , y_k , b_{ij} , $Q_{\max}$ and the decision variables x_j , q_{jk} , n_j remain the same. However, we add another dimension to the decision variable h , and define h_l , total balancing cost of chargers for the l^{th} scenario, $l = 1, \dots, N$.

Stochastic mixed integer linear programming model is as follows.

$$\begin{aligned}
\text{Minimize} \quad & \sum_{j=1}^m f_j * n_j + \sum_{l=1}^N h_l * P_l \\
\text{Subject to} \quad & \sum_{i=1}^m b_{ij} * x_j \geq 1 & \forall j \\
& S_j * \alpha_l \leq \sum_k q_{jk} * y_k & \forall j, l \\
& \sum_k q_{jk} = Q_j & \forall j \\
& Q_j \leq Q_{\max} * n_j & \forall j \\
& Q_j \geq Q_{\min} * n_j & \forall j \\
& h_l \geq c_k \sum_j q_{jk} & \forall k, l \\
& n_j \leq M * x_j & \forall j \\
& x_j \in \{0, 1\} & \forall j \\
& n_j \geq 0, \text{ integer} & \forall j \\
& q_{jk} \geq 0, \text{ integer} & \forall j, k
\end{aligned}$$

New objective function represents the total expected charging station location costs. The first part of the objective function is same as before since the fixed opening cost f_j does not depend on the value of α . The second part is the expected total charger cost, where expectation is computed by summing all possible costs for each scenario weighted by the associated probabilities.

The following changes are made to the following constraint:

$$\begin{aligned}
S_j * \alpha_l &\leq \sum_k q_{jk} * y_k & \forall j, l \\
h_l &\geq c_k \sum_j q_{jk} & \forall k, l
\end{aligned}$$

These constraints are to compute the total charger costs associated with each scenario α_l . α changes between 0.01 and 0.08 with uniform distribution. l values of α_l are 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 1000, 2000, 3000, 4000 and 5000. Gurobi solver is used to get results. Gurobi calculates and sets most options at the best values for specific problems. Result of stochastic model is:

l values	Number of Fast Charger	Number of Medium Charger	Number of Slow Charger	Cost
5	1996	3946	19110	19966110
10	2023	4044	20226	20232130
20	2310	4620	23092	23102395
30	2310	4620	23093	23102395
40	2310	4620	23092	23102395
50	2310	4620	23092	23102395
60	2310	4620	23092	23102395
70	2310	4620	23092	23102395
80	2310	4620	23092	23102395
90	2310	4620	23092	23102395
100	2310	4620	23092	23102395
200	2310	4620	23092	23102395
500	2310	4620	23092	23102395
1000	2310	4620	23092	23102395
2000	2310	4620	23092	23102395
3000	2313	4627	23135	23137415
4000	2313	4627	23135	23137415
5000	2313	4627	23135	23137415

Table 5.21: Number of chargers with changing α_l value

$\alpha_l, l=5$

Arnavutkoy	4	Atasehir	2	Avcilar	4
Bagcilar	17	Bahcelievler	2	Bakirkoy	1
Basaksehir	6	Bayrampasa	6	Besiktas	1
Beykoz	1	Beylikduzu	1	Beyoglu	1
Buyukcekmece	1	Catalca	1	Cekmekoy	4
Esenler	10	Esenyurt	11	Eyup	1
Fatih	2	Gaziosmanpasa	11	Gungoren	7
Kadikoy	2	Kagithane	2	Kartal	5
Kucukcekmece	15	Maltepe	9	Pendik	11
Sariyer	1	Sancaktepe	6	Silivri	1
Sultanbeyli	11	Sultangazi	6	Sile	1
Sisli	1	Tuzla	2	Umraniye	3
Uskudar	2	Zeytinburnu	6		

Table 5.22: Number of charge stations when $l=5$
 $\alpha_l, l=10$

Arnavutkoy	4	Atasehir	2	Avcilar	4
Bagcilar	16	Bahcelievler	2	Bakirkoy	1
Basaksehir	6	Bayrampasa	6	Besiktas	1
Beykoz	1	Beylikduzu	1	Beyoglu	1
Buyukcekmece	1	Catalca	1	Cekmekoy	4
Esenler	10	Esenyurt	11	Eyup	1
Fatih	2	Gaziosmanpasa	11	Gungoren	7
Kadikoy	2	Kagithane	2	Kartal	5
Kucukcekmece	15	Maltepe	9	Pendik	10
Sariyer	1	Sancaktepe	6	Silivri	1
Sultanbeyli	11	Sultangazi	6	Sile	1
Sisli	1	Tuzla	2	Umraniye	3

Uskudar	2	Zeytinburnu	6		
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Table 5.23: Number of charge stations when $l=10$ $\alpha_l, l=20$

Arnavutkoy	5	Atasehir	2	Avcilar	5
Bagcilar	19	Bahcelievler	2	Bakirkoy	1
Basaksehir	7	Bayrampasa	7	Besiktas	1
Beykoz	1	Beylikduzu	1	Beyoglu	1
Buyukcekmece	1	Catalca	1	Cekmekoy	4
Esenler	12	Esenyurt	13	Eyup	2
Fatih	2	Gaziosmanpasa	12	Gungoren	8
Kadikoy	2	Kagithane	2	Kartal	5
Kucukcekmece	17	Maltepe	11	Pendik	12
Sariyer	1	Sancaktepe	7	Silivri	1
Sultanbeyli	12	Sultangazi	7	Sile	1
Sisli	1	Tuzla	2	Umraniye	6
Uskudar	2	Zeytinburnu	7		

Table 5.24: Number of charge stations when $l=10$ $\alpha_l, l=30,40,50,60,70,80,90,100,200,500,1000,2000$

Arnavutkoy	5	Atasehir	2	Avcilar	5
Bagcilar	19	Bahcelievler	2	Bakirkoy	1
Basaksehir	7	Bayrampasa	7	Besiktas	1
Beykoz	1	Beylikduzu	1	Beyoglu	1
Buyukcekmece	1	Catalca	1	Cekmekoy	4
Esenler	12	Esenyurt	13	Eyup	2
Fatih	2	Gaziosmanpasa	12	Gungoren	8
Kadikoy	2	Kagithane	2	Kartal	5
Kucukcekmece	17	Maltepe	11	Pendik	12
Sariyer	1	Sancaktepe	7	Silivri	1
Sultanbeyli	12	Sultangazi	7	Sile	1
Sisli	1	Tuzla	2	Umraniye	6

Uskudar	2	Zeytinburnu	7		
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Table 5.25: Number of charge stations when $l = 30, 40, 50, 60, 70, 80, 90, 100, 200, 500, 1000, 2000$

$\alpha_l, l = 3000, 4000, 5000$

Arnavutkoy	5	Atasehir	2	Avcilar	5
Bagcilar	19	Bahcelievler	2	Bakirkoy	1
Basaksehir	7	Bayrampasa	7	Besiktas	1
Beykoz	1	Beylikduzu	1	Beyoglu	1
Buyukcekmece	1	Catalca	1	Cekmekoy	5
Esenler	12	Esenyurt	13	Eyup	2
Fatih	2	Gaziosmanpasa	12	Gungoren	7
Kadikoy	2	Kagithane	2	Kartal	5
Kucukcekmece	17	Maltepe	11	Pendik	13
Sariyer	1	Sancaktepe	6	Silivri	1
Sultanbeyli	12	Sultangazi	7	Sile	1
Sisli	2	Tuzla	2	Umraniye	5
Uskudar	2	Zeytinburnu	7		

Table 5.26: Number of charge stations when $l = 3000, 4000, 5000$

5.5.7. Discussion

Model 1 considers minimizing investment cost of a station. Investment cost includes fixed opening cost in different districts and charger cost. All customer demand is satisfied. Model does not consider customer behaviour while deciding charger type. Instead of customer, investor's budget is considered to decide chargers. Model tries to satisfy all demand with considering cost of a opening station and charger cost. If opening a station is cheap it opens another station with slow charger instead of adding a fast and expensive charger to the first station in that district.

Scenario is based on model 1 and includes electricity need. With this scenario, energy need in a district is calculated to understand electricity infrastructure need. This scenario does not change location of charge stations or number of chargers. Eight different acceptance rate is used to calculate number of chargers, charge stations in a district and electricity need.

Model 2 considers real m^2 costs in districts of İstanbul. Results show that instead of opening new stations, model have tendency to put fast chargers to satisfy all demand. Tendency to put fast chargers in stations occurs because of expensive m^2 costs. Different than model 1, there are less stations but more fast chargers. Even if fast chargers are more expensive than the slow and medium chargers, in this case it is better to use them instead of opening new stations.

Stochastic optimization is used because of uncertain demand of electric vehicles. It is applied to model 1. We use stochastic programming approach to incorporate the randomness of α .

Model 1 can be used if number of electric vehicle in a district is known. Model 2 can be used if m^2 prices of districts are drastically different than each other. It gives more realistic results than model 1 because opening cost of station is directly affecting the type of chargers in station. Stochastic approach can be used if number of electric vehicle in a district is not certain.

Chapter 6

CONCLUSIONS

This thesis focuses on environmental effects of conventional vehicles and how their replacement will effect the environment in terms of pollution and infrastructure need.

In this thesis, we analysed situation of Istanbul. Effects of passenger vehicles are analysed in main roads in aspect of noise and air pollution. Current situation was shown with graphs and tables.

Moreover, we analysed the data of road length and number of vehicles for Istanbul and develop a MILP formulation to design the network of charging stations to satisfy energy requirements. We created two models. In model 1, objective was to minimize the total station opening costs and electricity needs by deciding how many stations to open in each district of Istanbul. In model 2, different than the first model, constraint for electricity need is added and electricity cost is added to the objective function. We performed a sensitivity analysis on different parameters of the model. Infrastructure for environmentally friendlier vehicles requires extra electricity, parking places and chargers. In model 2, we created different scenarios with changing α manually and we added another cost constraint which considers meter square prices of a charging station. Also, we used stochastic programming model to incorporate the effect of a random acceptance rate parameter which denotes the proportion of vehicle owners who plan to use electrical vehicles.

This research can be extended in several directions. First, different scenarios can be created and applied to the model. Scalar parameters can be changed or stochastic approach can be applied to another parameter except α .

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