ELECTRICAL AND FINANCIAL ANALYSES OF EV CHARGING STATIONS BY STATISTICAL AND PROBABILISTIC SIMULATION

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ELECTRICAL AND FINANCIAL ANALYSES OF EV CHARGING STATIONS BY STATISTICAL AND PROBABILISTIC SIMULATION

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To my family...

ABSTRACT

Increasing environmental pollution with the increase of vehicles that have internal combustion engines has led people to alternative methods due to the transportation sector's share in environmental pollution. Last decade, Researches have been increasıng sharply in this field to improve E-Mobility usage. On the other hand, automobile manufacturers who are producing internal combustion engines have announced that they will stop their R&D studies as of 2025. It is predicted that 300-350 million electric vehicles will be in traffic in the world by 2040. It is estimated that the energy demand created by this number of electric vehicles can be met with 350 million electric vehicle charging stations. In Turkey, it is estimated that 10 million electric vehicles will be on the roads in 2040. New charging stations will be established to meet the demand for electric vehicle charging stations that arise with the increase in electric vehicles. However, due to the lack of historical data, it is not entirely known how these stations will affect the electrification system in the region where they are installed in public areas. On the other hand, the number of stations does not increase rapidly due to the lack of a comparative example for investors who want to establish an electric vehicle charging station. In order to solve this problem, a simulation was created based on probabilistic and statistical analysis. As a result of the simulation, a realistic data set was created, and the effect of the new electric vehicle charging stations was discussed electrically and financially. There are two cases for using the simulation. One of the stations chosen for the simulation in the study is the shopping mall's car park, and another is a rest area on the Istanbul-Izmir highway.

ÖZETÇE

Dünyada fosil yakıtla çalışan motorlu araçların artışıyla birlikte yükselen çevre kirliliği, insanları alternatif yöntemlere sevk etmiştir. Ulaşım sektörünün çevre kirliliğindeki payı dolayısıyla elektrikli araçların kullanılması iyi bir yöntem olarak görülmektedir. Son on yılda elektrikli araç sayısının yükselişi bu yöndeki çalışmaları hızlandırmıştır. Diğer bir yandan içten yanmalı motor kullanan otomobil üreticileri 2025 yılından itibaren AR-GE çalışmalarını durduracağını açıklamışlardır. Dünyada 300-350 milyon elektrikli aracın 2040 senesinden itibaren trafikte yer alması öngörülmektedir. Bu sayıdaki elektrikli aracın oluşturacağı enerji ihtiyacı talebinin 350 milyon elektrikli araç şarj istasyonuyla birlikte karşılanabileceği tahmin edilmektedir. Türkiye'de ise 10 milyon elektrikli aracın 2040 senesinde yollarda olacağı tahmin edilmektedir. Elektrikli araçların artışıyla birlikte ortaya çıkan elektrikli araç şarj istasyonu talebini karşılayabilmek için yeni şarj istasyonları kurulacaktır. Bu istasyonların halka açık alanlara kurulumu sırasında kurulduğu bölgedeki elektrifikasyon sistemine nasıl bir etki yapacağı geçmişe dönük veri eksikliğinden dolayı tamamıyla bilinememektedir. Diğer bir yandan elektrikli araç şarj istasyonu kurmak isteyen yatırımcıların karşılaştırabildiği bir örnek olmamasından dolayı istasyon sayısı hızla artmamaktadır. Bu soruna çözüm olmak amacıyla olasılıksal temellere dayanılarak bir simülasyon oluşturulmuştur. Simülasyon sonucunda gerçeğe yakın bir veri seti oluşturarak, yeni kurulacak elektrikli araç şarj istasyonlarının yaratacağı etki elektriksel ve finansal açıdan ele alınmıştır. Çalışmada simülasyon için seçilen istasyonların biri şehir içinde sık ziyaret edilen alışveriş merkezinin otoparkı, diğeri ise İstanbul-İzmir otoyolu üzerinde bulunan bir benzin istasyonudur.

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CHAPTER I

INTRODUCTION

Carbon emissions have been increasing day by day from the beginning of the 1900s to the current days in the world, which causes severe damage to the ecosystem. Carbon emissions increased by 90% from 1970 to 2014[6]. One of the most significant stakeholders causing greenhouse gas emissions is the transportation sector for moving people and goods. The most frequently used vehicles in the transportation sector are internal combustion vehicles (ICE) utilizing diesel and petrol fuels. ICE vehicles produce 27% of the Europe's toxic gas emissions[7]. The rapid increase in the sales of ICE motor vehicles will create resource problems in the future, hence there will be social, political, financial and environmental problems. Fossil fuel is the most common source of industrial processes due to fossil-based combustion engines being very spread. Fossil-fuel uses percentage is only 8% except gasoline and diesel. According to the data of the Turkish Statistical Institute (TUIK), the number of motor land vehicles registered to traffic was 8 million 655 thousand at the end of 2002. While the total number of vehicles reached 16 million 89 thousand in 2011, it exceeded 24 million 144 thousand by the end of last year. As of the end of October, the number of registered electric vehicles in Turkey is only 0.6% of the total number of vehicles that is 84302[8]. In recent years, it has been seen that countries have taken actions to change this problem due to this pollution caused by the transportation sector. Increasing demand for fossil fuels in order to meet the increasing demand in the transportation sector is of economic and political significance for countries. Financial difficulties will arise for countries that do not have access to fossil resources in their geopolitical position. The increase in fossil fuel prices and the harm caused to the environment increase the demand for electric vehicles. Electric vehicle usage is a good solution because the energy to be produced with renewable resources can be used in these vehicles. In addition, EV has various advantages such as low maintenance cost, noise cancellation, and charging at home because of these reasons, individuals can change their ICE behaviors in the following years. Some countries will ban the sale of ICE vehicles in major cities from 2035, such as the USA. Thus, all vehicles in the transportation sector will be fulfilled by electric vehicles after a while.

1.1 Problem Statement

The most important factor affecting the spread of electric cars is the charging stations. In order to determine the number of charging stations, it was determined that there should be a charging unit for each EV. The number of charging units in big cities is increasing day by day. It is understood that the spread of electric cars in crowded and low air quality cities will be faster under the leadership of local governments and national governments. It is estimated that approximately 350 million electric vehicles will be on the roads by 2040 in the world[9]. In Turkey, this figure is estimated to be around 10 million in 2040. In order for these 10 million vehicles to circulate in traffic properly, 10 million charging units are required[10]. Today, it is seen that EVCS companies want to have experience by placing several charging units in regions, especially in big cities. Tthe number of EVCS in the U.S. can only meet 30% of the future needs, despite the rapid establishment of charging stations[11]. One of the most fundamental reasons electric cars are not widespread is the lack of sufficient charging stations. Consequently, rapid increases in charging stations should be ensured, the energy infrastructures of the regions should be made physically suitable, and legal regulations should be created in the same way. Unfortunately, the EV sector does not have the experience and data to meet this need.

1.2 Objective of Thesis

In this study, the simulation has been developed to generate real-like E-Mobility data based on the region using probabilistic functions due to the lack of historical data on electric vehicles. The number of EVCS should raise to meet the requirements of EV charging in order to be used sufficiently with the increase of electric vehicles. Therefore, two cases have been used in the simulation. First, The shopping center's parking lot located in the Asian continent in Istanbul was used for Case I. It is assumed that customers who want to come to the shopping center and charge their EV in Case I will benefit from EVCS for at least 10 minutes of charging. On the other hand, the EVCS in Case II is a rest area located on an inter-urban highway, and the simulation is set so that customers who come here to charge their vehicles will charge their vehicles for at least 25 minutes. There are various modules to create E-Mobility data, such as event generator, vehicle arrival module, and departure of a vehicle generator. The event generator is used to generate an event that is very similar to real-life such as an incoming customer, outgoing customer, or customer waiting in the queue. Case I & II were used to enable electrical and financial analysis in any region using Google Popular Times data. The simulation makes electrical and financial analysis of whether the station is suitable for the electricity distribution line in the region, depending on the number and characteristics of the station to be installed in the EV using the E-Mobility data.

CHAPTER II

LITERATURE REVIEW

Nowadays, Individuals who want to meet their transportation needs as soon as possible are used to utilize internal combustion engine vehicles. Although this situation is considered normal for society, it will negatively impact the world in the future. For instance, the transportation sector is responsible for 28% of greenhouse gas emissions in the United States of America[12]. When using combustion engine vehicles, toxic gas is emitted to the outside, which is one of the main causes of global warming. It has an effect of 64.7% on the pollution of the world[13]. In order to reduce the effects of this pollution, some improvements are made in combustion motor vehicles, but the release of toxic gas cannot be prevented. Electric vehicles are a sufficient method to avoid air pollution in vehicles. Since electric vehicles do not consume any fossil fuels, they do not emit toxic gas. Besides, the consumption of fossil fuels has been increasing day by day that will restrict the availability of fossil fuels in the future. For this reason, electric vehicles need to be adapted to the transportation sector, but the important issue to be focused on here is whether the electrification infrastructure in the regions where the charging stations will be established is sufficient.

2.1 Electric Vehicles

The first known electric motor and vehicle in history was invented in Vermont, America by Thomas Davenport in 1835. The vehicle was a small locomotive using two electromagnets, a pivot, and a battery. Many electric vehicles have been developed since this date, but they did not become widespread until the 2000s, the reason is that they have less range and speed compared to internal combustion engines[14]. Electric vehicles are more energy-efficient than ICE vehicles that are 17%-21% efficient[15], while EVs are 59%-62% efficient. There are three main EV categories which are Plug-in Hybrid Electric Vehicles (PHEVs), Battery Electric Vehicles(BEV) and Fuel Cell Electric Vehicles(FCV's)[16]. The fuel/battery type is the factor that determines the type of electric vehicle. BEVs have been providing the power to the drive-train from only the battery; therefore, these types are called Battery Electric Vehicles. On the other hand, PHEVs provide power to the drive-train not only from the battery but also using an internal combustion engine and the battery.

2.1.1 Plug-in Hybrid Electric Vehicles (PHEVs)

Plug-in hybrid electric vehicles (PHEVs) provide the energy they need from batteries and fossil fuels. These types of vehicles have an internal combustion engine and an electric motor. In this way, vehicles can travel longer than electric vehicles and normal combustion engine vehicles[17].

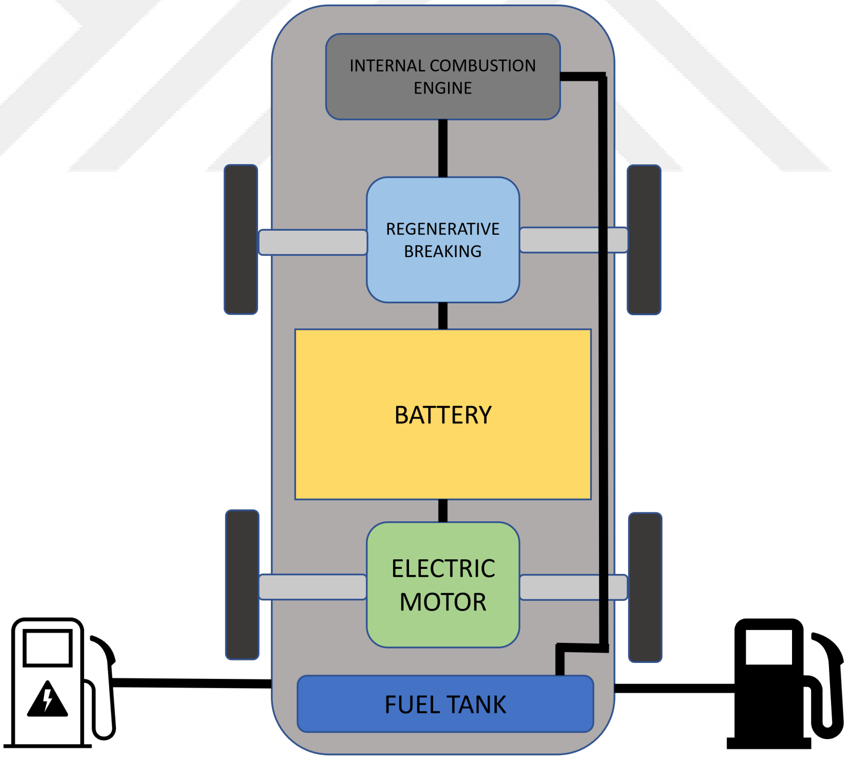


Figure 1: Structure of the PHEV

PHEVs cannot be defined as zero-carbon emission vehicles, although these vehicles give individuals a chance to travel by consuming fossil fuels or electrical energy. Figure 1 illustrates that key componts of a PHEV, which is include

ICE, regenerative breaking system, battery, fuel tank and electric motor. It has an engine, as in vehicles with ICE, connected to the vehicle's front powertrain to move. They can move around using fossil fuel as a typical ICE vehicle. In addition, it has a battery in the middle of the vehicle, as is usually seen in electric vehicles. The electric motor is connected to the rear power transmission. PHEVs can travel from one point to another using only electrical energy. PHEV owners can charge their vehicles or buy diesel or petrol, depending on their wishes. Although it seems like an advantage in these vehicles to have both ICE and electric motors, they are inefficient vehicles in terms of fuel or energy consumption because they are heavier in weight than BEV or ICE vehicles. Also, their battery capacity is more limited than BEVs, so that they can travel shorter distances. Generally, this type of vehicle can travel about 80 km using only the electric motor, which means it is a sufficient distance for going from one point to another in the urban. However, if the battery does not allow the vehicle to move in case the battery dies, the ICE is automatically activated.

2.1.2 Battery Electric Vehicles(BEV)

BEVs provide electricity to move from batteries that include chemical energy. In basic principle, BEVs electric motors convert chemical energy to electrical energy[18]. They have 100 to 500 km range that depends on driving behavior, battery capacity, weather condition, vehicle features, road type, and car condition[19]. The vital component of BEVs is battery that's capacity is crucial, which has affected the range of journeys as in Table 1. BEVs do not emit toxic gases thanks to the battery, unlike vehicles with internal combustion engines. Table 7 shows that charging times. There are variety of configuration for motor, gear and differential of vehicle. There are varieties of designing configurations for motor, gear, and differential. For instance Tesla Model 3 has three different type of electric motor place.Figure 2 (a) illustrates two induction motors for the rear two tires. The second shows that there are also two motors, but they have distributed one in the rear and one in the front tire. Last one is the most powerful one that has three motors occur more power. The last one is the most powerful one that has three motors occur more power[5].

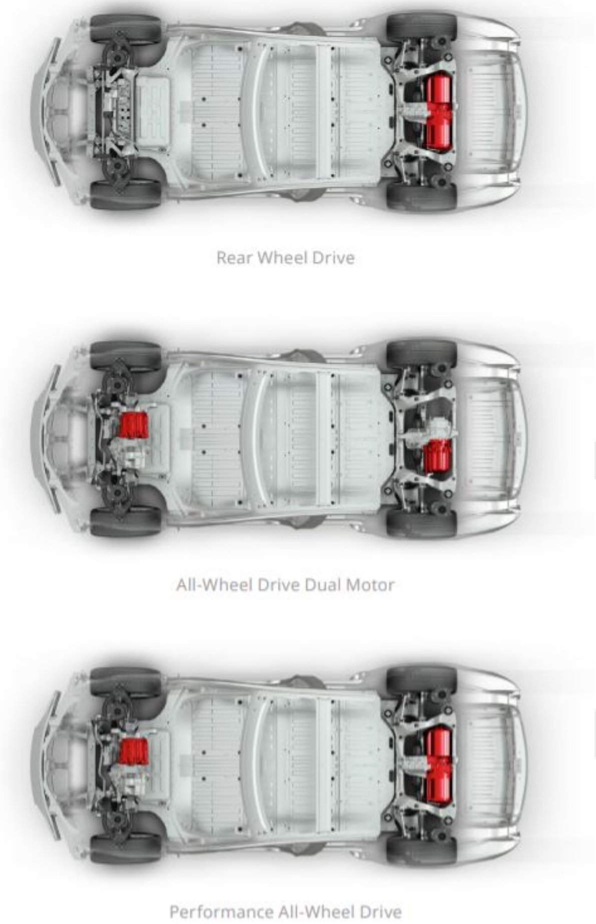


Figure 2: Tesla Model S [5]

Table 1 shows that the demand for electric vehicles in Turkey is increasing rapidly. As of the end of March 2021, the sales of electric vehicles increased to 1773 in total[1].

2.2 Electric Vehicles Charging Infrastructure

Another point is as important as electric vehicles, which are the charging units of electric vehicles. Charging units are used to provide the energy needed by electric vehicles, but the time spent at the station is longer than internal combustion engines. Reducing the charging time is a crucial issue on this topic thus, charging units are divided into many groups for themselves, and the differences may

Table 1: Electric Vehicle Sales in Turkey until March 2021 [1]

EV Brand	2015	2016	2017	2018	2019	2020	2021/3	Total
BMW i3	83	24	35	37	50	39	3	**271**
BMW iX3	-	-	-	-	-	-	1	**1**
Jaguar I-Pace	-	-	-	38	119	178	2	**337**
Mercedes Benz EQC	-	-	-	-	-	42	58	**100**
Mini-Cooper SE	-	-	-	-	-	103	3	**106**
Porsche Taycan	-	-	-	-	-	303	135	**438**
Renault Zoe	36	20	42	79	31	135	103	**446**
Smart EQ ForFour	-	-	-	1	22	9	-	**32**
Smart EQ ForTwo	-	-	-	-	-	35	7	**42**

vary in terms of voltage, energy and current they provide. There are differences in standards for charging units in America (SAE) and Europe (IEC)[20].There are different classifications within these two standards; for example, 'Level' is used to classify AC levels in the SAE standard, and 'Mode' is used in the IEC standard[21].In Europe IEC 61851-1 standart has 4 different charging modes[22]. There is also a distinction between modes, 3 modes are for AC and only set the standard for single-mode DC. These modules are divided into two within themselves, this distinction varies according to the number of phases. For Mode1, voltage up to 250V and current up to 16A are provided in a single phase. In 3 phases, only the voltage differs and goes up to 480V. Voltage values for Mode-2 are the same as Mode-1, only the current increases to 32A for all phases.In Mode-3, on the other hand, the voltages remain the same and the current can go up to 250A. Since there is no phase in DC, the voltage can increase to 1000V and the current to 400A[23].

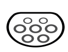
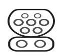
2.2.1 AC Charger

AC chargers provide single-phase alternating current, but since the battery can be charged in DC, an AC/DC converter is needed.In IEC standard, AC Chargers have two main modes that are Mode 1 and Mode 2. These are able to use in private and public places and provide energy 3.7 kW to 44 kW[24]. In fact, converters, which are AC/DC, have a crucial impact while charging the electric vehicle because they have a power limit.

2.2.2 DC Charger

DC chargers can charge the vehicle's battery faster than AC chargers due to this type is called fast charging. EV batteries are charged with DC; therefore, DC charging units do not need additional converters while charging the battery. On the other hand, electricity grid provides three phase voltage up to 480 V with AC. DC chargers have been converting AC to DC via rectifier which are provided power factor correction[25]. DC charging unit can vary the voltage for battery packs as the output is DC. The main advantage of DC charging units is that EV owners spend less time charging their vehicles. Table 2 demonstrates that DC chargers types are used on the EV market. GB/T coupler inlet is suitable for China, CCS Type 1 is using in North America, CCS Type 2 is using in Europe and Australia. Although, CHAdeMO coupler inlet is common for EVs. According to CHAdeMO Association Protocol, there are 25300 charge points in 71 countries in the world[26].

Table 2: DC Charging Systems Standards [2]

Standart	**CHAdeMo** IEEE 2030.1.1 IEC 62196-3	**GB/T** GB/T 20234.3 IEC 62196-3	**CCS Type 1** SAE J1772 IEC 62196-3	**CCS Type 2** IEC 62196-3	**Tesla**
Coupler Inlet					
Maximum Voltage	1000 V	1000 V	600 V	1000 V	410 V
Maximum Current	400 A	250 A	200 A	200 A	330 A
Available Power	400 kW	120 kW	150 kW	175 kW	135 kW

2.2.3 DC Fast Charger

DC charging units are used for charging electric vehicles in industrial areas. The main reason for its use in this area is that it provides the energy need of vehicles in less time than AC charging units. However, they have more power needs and costs than AC and normal DC chargers.

Table 3: Technical Features of DC Chargers [3]

Brand	*Power*	Supported Protocols	Input Voltage	Output Voltage	Output Current
ABB Terra 53	50 kW	CCS Type 1 CHAdeMO 1.0	480 Vac	200-500 V	120 A
Tritum	50 kW	CCS Type 1 & 2 CHAdeMO 1.0	380-480 Vac	200-500 V	125 A
Tesla	135 kW	Supercharger	380-480 Vac	50-410 V	330 A
Evtec	150 kW	Combo 1 CHAdeMO 1.0	400 Vac±10%	170-500 V	300 A
Phioning	120 kW	GB\\T	480 Vac±15%	200-750 V	240 A
ABB Terra HP	350 kW	Combo 1 CHAdeMO 1.2	400 Vac±10%	150-920 V	375 A

2.3 *Electric Vehicles Batteries*

The battery is the critical component for EVs because that determines the range of the EV by storing an amount of energy. Batteries are divided into rechargeable and non-rechargeable batteries in the general concept. Non-rechargeable batteries are not used in electric vehicles, on the other hand, rechargeable batteries are also divided into various classes such as Lead-Acid, Nickel Metal Hydride ,and Lithium-ion batteries[27].

Table 4: Comparison Table of Battery Types

Features	**Lead-Acid**	**NiMH** (Nickel-Metal Hydride)	**Li-Ion** (Lithium-Ion)
Cost	Low	Medium	High
Life Cycle	Low	Low	High
Memory Effect	(-)	High	Low
Power Density	Low	High	High
Energy Density	Low	High	High
Recyclable	No	Yes	Yes

Table 3 shows that the comparison of batteries as some features. Lead-acid is cheaper than other batteries, but it is more disadvantageous than other batteries in terms of other features. Although NiMH seems usable in terms of its features, its life cycle is 200-300 cycles when energy is consumed with a high load current. In the last decade, Li-Ion batteries have been the most widely used for EVs, as they are superior to other batteries in many aspects.

2.3.1 Lead-Acid

Lead-Acid battery technology in electric vehicles was common in the early 1990s. These batteries are not efficient for electric vehicles that do not emit toxic gas, because they have a limited life cycle and cannot charge or discharge the battery in a short time. In addition, batteries are faced with overheating problem when charging or discharging[28].Due to these disadvantages, research has been done to add these types of batteries to Hybrid vehicles. Supercapacitors have been used to solve the problems encountered[29].

2.3.2 Nickel Metal Hydride

Early of 20^{th} century, Lead-Acid batteries had altered to NiMH batteries since they were more efficient and durable. NiMH batteries have double energy density compared to lead-acid batteries, and the operating temperature range is extensive; therefore, they have durable to overcharge and recharge.Ni-MH batteries consist of two main components: the anode and the cathode. The anode is nickel lithium hydride or nickel lanthanum. The cathode is nickel oxide. The anode here is a hydrogen-absorbing composition. It can absorb a large amount of hydrogen, which is more than 1000 times the electrode volume on average. Then, lithium or lanthanum is added to the alloy to achieve complete stabilization. In 1999, Toyota has decided to change the battery for the Toyota Prius hybrid model that was the first mass-produced vehicle with electric propulsion.

2.3.3 Lithium-ion

Lithium-ion batteries are the most famous in the consumer electronics sector such as laptops, EVs, smartphones, etc. They have four main layers which are cathode, anode, electrolyte, and separator. In general, the charging of Li-ion batteries can define as when the electrically charged lithium atoms collect in the carbon layer, and after removing them from the charge, the electrons move towards the cathode while the realization of this cycle, electromagnetic power is produced. There are several advantages over other types of consumer electronic batteries. First, their weightiness is lighter than other rechargeable batteries. Second, they have a high energy density that provides more consumable power for electric vehicles, which is the main advantage of using Li-ion batteries. These batteries do not require maintenance to improve their performance. For instance, Ni-Cad batteries have a memory effect; hence, they require a periodic discharge. In addition, Li-ion batteries provide constant voltage, which is about 3.6 V. Also, the self-battery discharge rate is lower than other rechargeable batteries[18]. On the other hand, Li-ion batteries have disadvantages such as life-cycle. Battery manufacturers report that the life cycles of manufactured Li-ion batteries are between 300 and 500. According to the research, a Li-ion battery can fully charge and discharge 460 times at room temperature[30].

2.4 Simulations

In the last decade, with the rise of electric vehicles, research on their effects has been increasing. Due to the lack of historical data that can shed light on these studies, it is tried to get the closest results with stochastic methods. EV effects can be affected by many variables; these are the SoC status of vehicles during charging, charging locations, the battery's capacity, converters, and charging units[31]. The main purpose of the deterministic research is to test whether the system will be affected in the worst-case scenario[32]. Monte Carlo Simulation is used to simulate the EVs effect with different cases on the distribution line[33]. Benchmark distribution systems produced by the IEEE committee are used to study the impact of PHEVs or EVs on the electrical distribution network[34].

CHAPTER III

METHODOLOGY

This chapter clarifies the simulation's programming modules, logic, functions, and techniques in detail. The need for EVCS that will arise with the rapid increase in the number of EVs must be met, but since EVs have not been widely used in the past years, the effects of this need are not known. Therefore, a probabilistic simulation was developed that is similar to real-life. First, the simulation charging station provides the trend of visits in the region where it will be installed, using Google Popular Times data. Then it generates departure, arrival, or queue events from the station using the Poisson distribution with the event generator. Finally, electrical and financial analyses are performed with the data obtained from the simulation.

3.1 Probability Distribution Functions

Probability Distribution Functions(PDFs) are used to find a relationship between a random variable and its probability. There are different types of PDFs which has two main part such as discrete and continuous variables. The probability mass function is used to calculate that the probability of a discrete random variable is exactly equal to a certain value. For example, in the coin toss game, when a coin is tossed into the air, there are two possible outcomes, heads or tails. Therefore, the probability that the coin will land heads or tails will be 0.5. The Probability Density Function(PDF) is to find the expected value of a continuous variable in a particular range. It is necessary to integrate the probability density function in that range. In the simulation, there are three PDFs used for stochastic processes that are Gaussian, Beta and Poisson distributions.

3.1.1 Gaussian Distribution

The Gaussian or normal distribution is pattern data when a population or set of scores is measured with some randomness. Normal distributions are essential for statistics and often represent real-valued random variables whose distributions are unknown.

3.1.2 Beta Distribution

Beta Distribution is a continuous probability distribution that has interval range between 0 to 1. The distribution shape can control by two variables which are α and β. The simulation is used static numbers to get SOC range for EVs,[α:3.7, β:5] and [α:2, β:5] for each cases. Table 3 demonstrates the probability of SOC of arrived vehicles.

3.1.3 Poisson Distribution

Poisson distribution is used for the probability of the number of occurrences in a specific time interval that the discrete probability distribution. The Poisson distribution is frequently used in some researches that have queue probabilities[35, 36, 37]. The simulation creates events that is the arrival of vehicles into charging stations.

$$p(x, \lambda) = \frac{e^{-\lambda}\lambda^{x}}{x!} \text{ for } x = 0, 1, 2, \cdots \tag{1}$$

3.2 Input Parameters

There are several parameters set into the simulation to work properly. The main purpose of this simulation is to create data set that is much as similar to accurate data. However, the simulation is based on a stochastic process to generate E-Mobility data. Therefore, the simulation needs parameters to use in a randomized process. Event generator generates events such as incoming vehicle to EVCS. First, if the vehicle charges with any charger, the simulation has to create initial SoC applied by beta distribution. The parameters of the beta distribution are accepted as [α:3.7, β:5] for the shopping mall in the city[38]. The initial SoC is set closer to zero for the charging station on the highway by contrast with the shopping mall, [α:2, β:5] as can be seen in Figure 3.

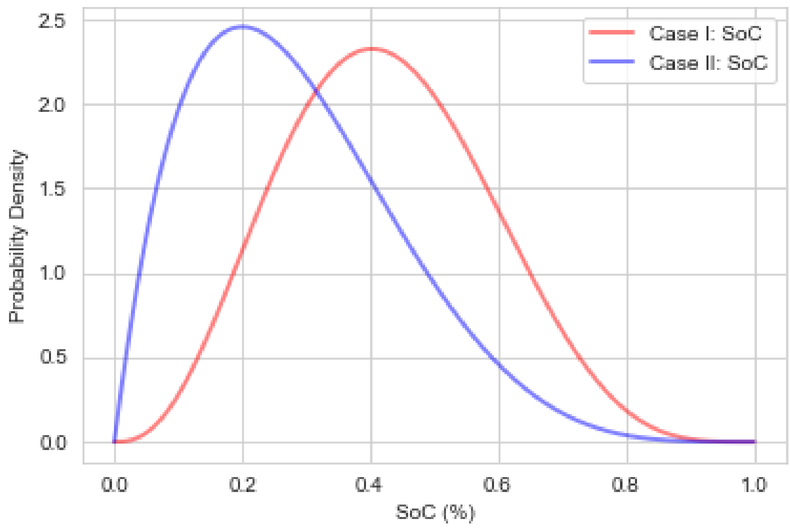


Figure 3: Beta Distributions of Case I & II

The maximum charging of the vehicles is set up to 80% of the vehicle battery capacity because after this capacity, and the charging times become extremely slow [39]. Thus, EV owners are not expected to wait on the station that long. There are two constraints for minimum charging times that are applied for EVCSs. EV owners have to charge their vehicles greater than ten minutes in the shopping mall that is located in the city. On the other hand, if EV owners want to charge their vehicles into a charging station located on the highway, the simulation is set to minimum charging time to twenty-five minutes. Herewith, the simulation result has been getting more accurate. Secondly, in Turkey, eight different vehicles sold were used in the simulation. Each of these vehicles has different technical characteristics, such as battery capacity. This situation also creates differences in the users' requests, so each of the vehicles has priorities according to the station type. For example, when the Jaguar I-Pace arrives at the station, its first priority is the 50 kW charging socket, as you can be seen in Table 5. Renault ZOE V1 is not a priority as it does not able to charge with DC charging unit.

Table 6: Charging Sockets Pricing Tariffs [4]

Charging Sockets	Charging Price (TL/min)	Charging Price (TL/kWh)
22 kW AC	0.55	1.50
24 kW DC	1.00	2.50
50 kW DC	1.65	1.98

Table 5: Charging Socket Priority

EV Brand	22 kW AC	24 kW DC	50 kW DC
Nissan LEAF V2	Third	First	Second
VW eGolf V2	First	Second	Third
Renault ZOE V1	First	-	-
Hyundai Ioniq	First	Second	Third
BMW i3 V2	First	Second	Third
KIA Soul V1/V2	First	Second	Third
Jaguar I-Pace	Third	Second	First
TOGG	Third	Second	First

Thirdly, the prices used by E-Sarj company are based on to calculate the revenues of EVCSs for financial analysis. As seen in Table 6, the charging stations used in Case I and II are priced on a minute basis if EVs use the charging station. In minute-based pricing, if the vehicle remains at the charging station when the vehicle is fully charged, EV owners continue to pay as if they are charging. EVCS owners pay the electricity distribution company is 1.22 TL per kWh for consuming the electricity.

3.2.1 Google Popular Times

The simulation does not have E-Mobility data to forecast the demand of charging station popularity. Therefore, Google Popular Times data is used to ensure the visit duration and popularity of a charging station place. In the light of popularity data, the probability of arriving electric vehicles is calculated by Poisson

Distribution.

3.3 Simulation Modules

The simulation models the charging of various electric vehicles with different charging units based on the popularity data of rest areas installed in commercial areas. The mobility of the vehicles coming to the station is based on a stochastic basis. Therefore, the simulation consists of events that can be encountered at any charging station in daily life. The simulation is developed with six modules that are event generator, vehicle feature module, vehicle arrival module, vehicle departure module, queue creation and tracking module and electricity calculation module.

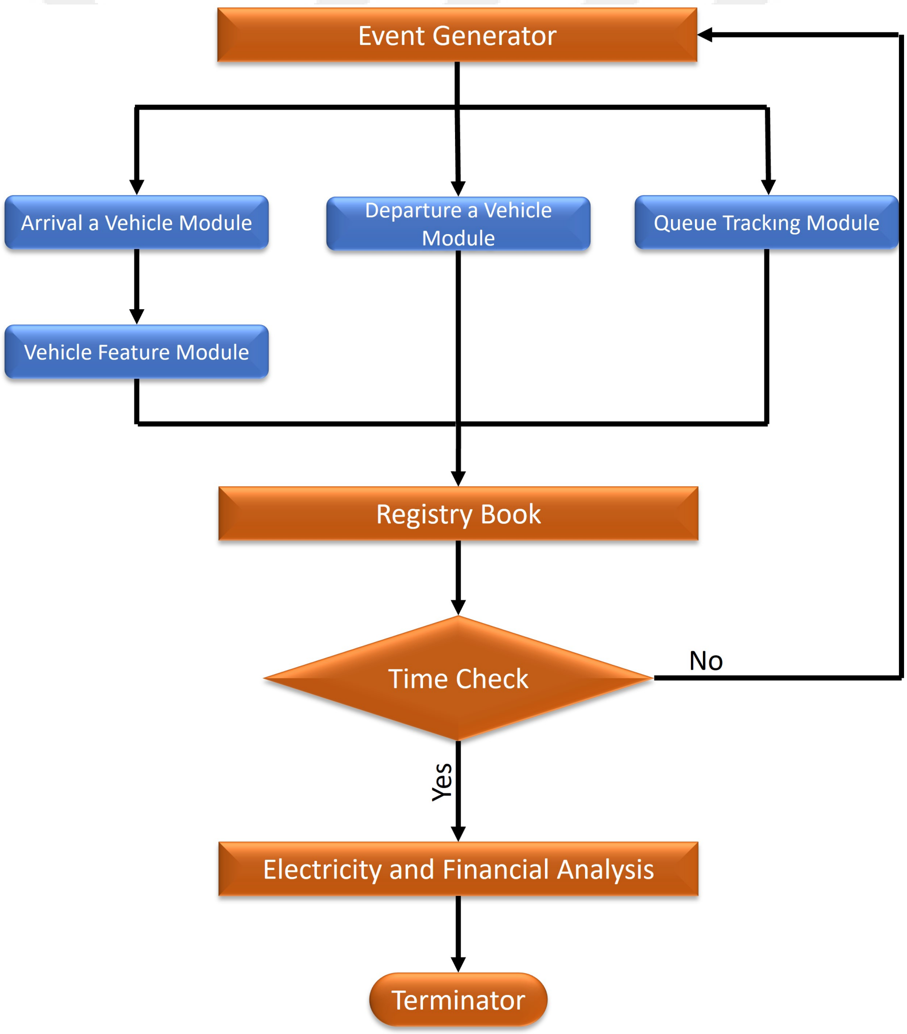


Figure 4: Methodology of Simulation

3.3.1 Event Generator Module

The event generator module has been generating three events by tracking the time and current number of vehicles in the charging station: the arrival of a vehicle, departure of a vehicle, and departure of a vehicle waiting in the queue. This module generates events by importing the data obtained from Google Popular Time data to the Poisson distribution. The Poisson distribution determines the rate of arrival (λ) vehicles every sequentially two hours due to the vehicle arrival rate of the event generator being determined. On the other hand, the simulation shall be closest to daily life. For example, EV owners can leave the station when they have a parking lot or waiting in the queue; therefore, the event generator generates a departure event from the station using the standart uniform distribution probability from the vehicles in the parking lots or the queue. The event generator cannot generate a departure event if there are no vehicles in the queue or parking area. The event generator does not generate a departure event if there are no vehicles in the queue or parking area. There is a registry book produced by the event generator module that records each event.

3.3.2 Vehicle Feature Module

This module includes different electric vehicles with various features. Vehicles which have chosen are selling in Turkey market. However, vehicles have different charging limits because of their charging battery standards. Therefore, the module has a feature that priority preference depends on the battery capacity. Adding this feature increases the simulation's similarity to an actual charging station because customers will not want to charge their vehicles for hours; thanks to that feature, long charging times are avoided, and the accuracy of the simulation is increased. This module calculates the SoC for each EV by using beta distribution between 0% to 100%. According to the study, the beta distribution has two parameter that are α=3.7 and β=5 by virtue of a probability density function (PDF) for SoC determination is generated by electricity tariff structure and real vehicle usage pattern[40]. Table 7 demonstrates the current distribution. The probability of EVs are differ due to EVs prices. For instance, Nissan Leaf has higher probability rate than Jaguar I-Pace because it is cheaper than Jaguar I-Pace. To sum up, there are two main part in this module which are determining the each car SoC and the brand.

Table 7: Technical Characteristics of Vehicles

ID	$VehicleBrand$	$BatteryCapacity(kWh)$	AC	$24kwDC$	$50kwDC$
1	Renault ZOE	33	1 hr 30 min	1 hr 23 min	40 min
2	Nissan LEAF	32	4 hr 48 min	1 hr 20 min	38 min
3	BMW i3	26.4	3 hr 36 min	1 hr 6 min	32 min
4	Volkswagen eGolf	28.8	4 hr	1 hr 12 min	35 min
5	Hyundai Ioniq	22.4	6 hr 48 min	56 min	27 min
6	KIA Soul V2	24	6 hr 30 min	1 hr	29 min
7	Jaguar I-PACE	72	9 hr 42 min	3 hr	1 hr 26 min
8	TOGG	72	6 hr 32 min	3 hr	1 hr 26 min

3.3.3 Vehicle Arrival Module

When the event generator generates an arriving event of EV to the CS, this module will start several stochastic steps. First, It decides whether the incoming vehicle

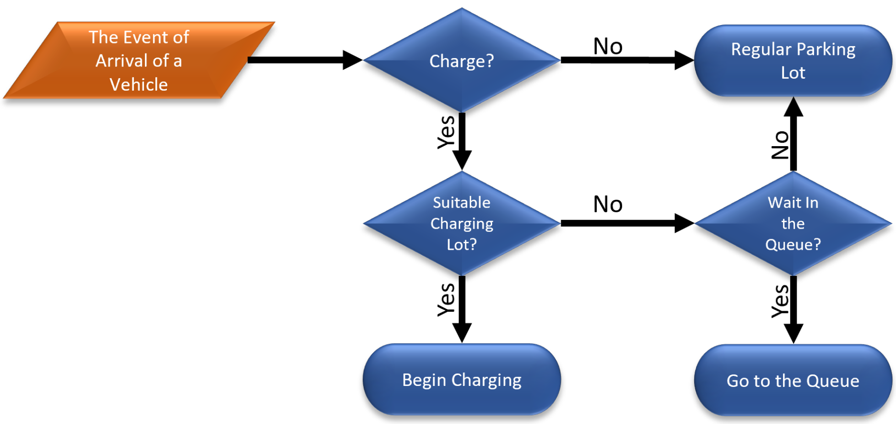


Figure 5: Methodology of vehicle Arrival Module

will be charged or not by tossing a coin, in other words, with a fifty percent chance. Then, if the vehicle's choice is not charging, it will directly move to the regular parking lot and be recorded to the registry book. However, if the intention is to charge the EV, this module will check the suitability of the CS parking lots using the priority preferences of EV such as AC charging, 24 kW DC charging, and 50 kW DC charging units. Then if there is a suitable CS parking lot, the vehicle will move to charge. On the contrary case, there will be two options: directly moving to the regular parking lot or moving to the queue by flipping a coin. This module has recorded all information in the registry book. The progress flow of Vehicle Arrival Module is shown in Figure 5.

3.3.4 Vehicle Departure Module

The event generator can also generate a departure event that completes the charge or before the 100% charge is completed. In this case, vehicle departure module is activated for the stochastic processes. First, the module is recording the departing vehicle into the registry book. This module then checks whether there is an electric vehicle waiting in the queue. If there is a vehicle in the queue, one vehicle. One of the vehicles in the queue is selected using three different methods: first vehicle, random one vehicle, and beta distribution. The reason is the action taken by cars looking for a space in a parking lot which includes a parking space. The selected EV will move to the CS parking lot and start charging. The progress of Vehicle Departure Module is shown in Figure 6.

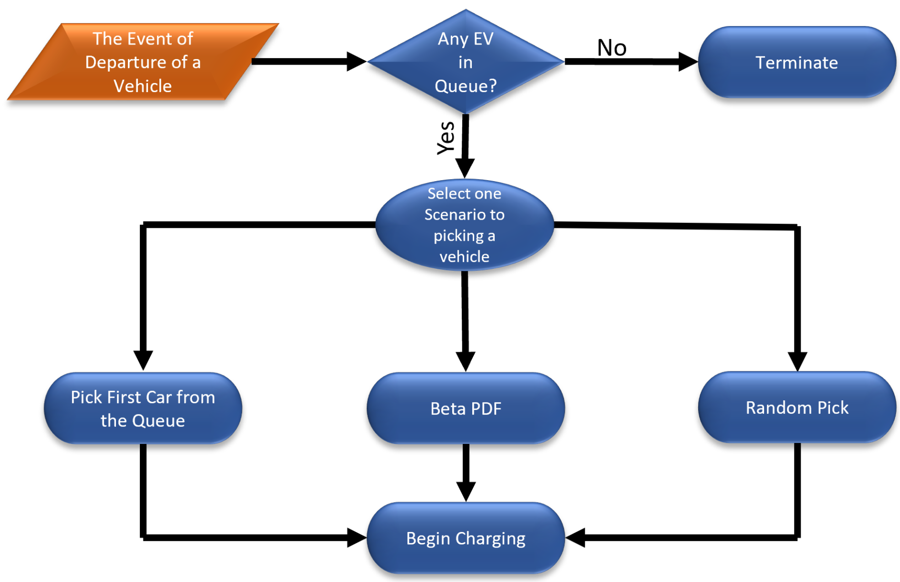


Figure 6: Methodology of Vehicle Departure Module

3.3.5 Queue Creation and Tracking Module

Generally, queues do not occur at a conventional gas station, but the likelihood of queuing increases due to long charging times for electric vehicles. Therefore queue creation and tracking module has been added to the simulation. In addition, there is a chance that vehicles can leave the queue without charging, thus preventing endless waiting. Firstly, the simulation will start this module if the event generator generates an event leaving a vehicle from the charging unit. Then, this module checks that is there any vehicle in the queue? If there is no vehicle in the queue, the module will be terminated. On the other hand, if there is a vehicle in the queue, the module will select one EV by beta PDF. All results have been recording in the registry book.

3.3.6 Electricity Calculation Module

The essential part of EVs is supplying electricity to charge their battery by using charging units. There are two possible ways to charge: alternative current(AC) and direct current(DC). Besides, there are different configurations, such as different current and voltage levels for each way. However, the main factor in vehicles choosing AC or DC charging units is the charging time because AC chargers charge slower than DC chargers. In this case, although DC charging units seem to be more advantageous, the prices of these units are higher than AC charging units. In this project, a charging unit provides three different types of charging such as AC, DC, and fast DC. AC has 22 kW, DC has 24 kW, and fast DC has a 50 kW power rating in charging. For instance, if there are three charging units in EVCS, fifteen different EVs might charge simultaneously. This module activated after the simulation is completed. All necessary information is provided from the registry book.

1. P_i^{max}: Maximum power capacity of the charging station, kW.

2. C_j^{max}: AC/DC converter capacity for each vehicle, kW.

3. S_j^0: The beginning of SOC, kWh.

4. B_j^{max}: The maximum battery capacity of EV, kWh.

$$T_j = (B_j^{max} - (B_j^{max} \times S_j^0 \div 100)) \times 60 \div P_i^{max} \tag{2}$$

$$T_j = (B_j^{max} - (B_j^{max} \times S_j^0 \div 100)) \times 60 \div C_i^{max} \tag{3}$$

$$E_j = (T_j \times P_i^{max} \div 60) \tag{4}$$

$$E_j = (T_j \times C_j^{max} \div 60) \tag{5}$$

If a vehicle has used one of the DC charging sockets, this module calculates the charging duration of the vehicle from Formula (2). Otherwise, this module is used Formula (3) to calculate the time duration. Besıdes, this module compares the parking time of the vehicle with the charging time; when the vehicle has been parked since the first arrival exceeds the time required to charge the battery fully, it directly calculates the energy by taking the time required for the battery to be fully charged. If the above case is not applicable, this module is used Formula (4) for the DC charging socket or Formula (5) for the AC charging socket to calculate energy.

3.4 Charging Tariffs

Electric vehicle charging tariffs are diverse for all countries, as are fuel purchased for internal combustion vehicles. The most critical factor is the electricity price (kWh/currency) in the region where the EVCS is located. If EV owners charge their vehicles at home, they will pay for the electricity directly from the main distribution; this may differ in commercial areas. Seven main charging tariff models are used in the world, which are ;

1. Fixed priced for each month.

2. Pricing based on kWh.

3. Pricing based on charge duration, $/hr.

4. Variable pricing as per charging unit type, kW.

5. Variable pricing based on frequency of visits during the day.

6. Pricing based on number of charges.

7. Pricing that includes all of the models mentioned above.

In the UK, EV owners can charge their cars in public charging points and EVCS instead of their homes. For example, there are 7000 charging points for EVs with different pricing tariffs that provide all AC and DC standards, such as Tesla supercharger, CCS, and CHAdeMO cables. In London, different prices are applied to customers. For example, one brand is charging 1.5 pounds for a 7 kW charging unit per hour. Also, EV owners have been paying 35 pounds for a 50 kW fast charging unit; moreover, there is one constraint: they only allow 60 minutes to stay for charging. On the other hand, ChangeYourCar offers customers two options for using the charging points it has established. The first one provides an opportunity to charge your vehicles by becoming a member, and the other offers the opportunity to charge and go without being a member. They charge 20 pounds for an annual membership. In London, members pay £12 per hour for 24kW charging, while non-members customers pay £18 per kWh[41].

In the USA, there are many different pricing models for charging EVs as in the UK. For example, there are two separate pricing models in a shopping mall similar to the first case used in this project. This EVCS uses a membership system and per-minute pricing. If the EV owner has a membership, they must pay a fee of $ 4 per month. The station provides two different charging options for EVs. Users can use CHAdeMO or CCS/SAE for a 50 kW charger and charging socket in the first option. For this service, members are required to pay $ 0.12 per minute, and non-members must pay $ 0.16 per minute. In the second option, the charging station has a 150 kW charging unit and a CCS/SAE charging socket only. Members are required to pay $ 0.24 per minute to benefit from this service, and users who do not have a membership have to pay $ 0.32 per minute[42].

In this project, cases taken as examples are two examples in Turkey, an urban shopping mall parking lot and a facility on the Istanbul-İzmir highway. Electricity is not allowed to be sold without government permission in Turkey due to government policies, hence minute-based pricing is applied for charging EVs. There are several companies providing to electricity for EV such as E-şarj, Voltrun and Zorlu Energy Solutions(ZES). Voltrun provides four charging unit types that are 3.7, 7.4, 11, and 22 kW AC charging units for commercial areas[43]. This company offers membership service, membership fee is 30 TL per month. Non-member users have to pay 5TL per charge to get charging service from Voltrun devices. Hereby, users pay per minute while charging their vehicles, these charges vary according to the type of charging unit. In addition, a service fee per minute and a service fee are paid at the time of charging to ECVS, for which the charging service is provided. For example, a 7.4 kW charging unit charges an electricity fee of 1.22 TL per minute, a service fee of 0.05TL, and an additional 8 TL transaction fee. ZES is following a different pricing strategy for charging units. They provide Type 2 (AC) and CCS/CHAdeMO (DC) charging units with 7.4 kW to 120 kW. The pricing policy of this company is entirely different from the previous ones. In the earlier examples, the charging cost varied depending on the subscription and the length of stay in the park. ZES, on the other hand, calculates the energy drawn by the battery and divides it by the parking time; thus, a fairer pricing policy is followed in case of power losses. After the power is calculated, the time parked is multiplied by the corresponding charge from Table 6. Non-member customers will pay a fixed fee of 115 TL if they used an AC charging station and 230 TL if they used DC to charge their EVs.

CHAPTER IV

ELECTRICAL ANALYSIS

The prevalence of zero-emission electric vehicles is increasing rapidly in order to prevent climate change, depletion of fossil resources, and environmental pollution. As a result of this, will occur extra load demand increase in the future. High power demands can adversely affect the grid or the working equipment of the grid. In light of this, there is no historical data that can be used to understand the effects of EVs. There are two different cases to examine the effects. This chapter describes the electrical results of Case I and Case II from applying the simulation to examine power and energy. Case I & II depict two dissimilar EV charging stations. Case I is assumed to be set up in the parking lot of a shopping mall, one of the largest shopping centers on the Asian side of Istanbul. This parking lot in the city has a total capacity of 1000 vehicles. In Case II, unlike the first case, there is an EVCS installed at a rest area located on a busy road between İstanbul and İzmir, which is not located in the city. It is assumed that there are three types of charging sockets in the charging units in the EVCS; these are 22 kW AC, 24 kW DC and 50 kW fast DC. This means that if there is a charging unit in the station, three EVs can be charged simultaneously. Therefore, the results were analyzed differently from one charging unit to four charging units.

4.1 Case I: (Downtown) Shopping Mall

The shopping center, which is the first case, is famous and frequently visited in the city on the Asian side of Istanbul. The simulation was provided the results by repeated 100 times for a Sunday. In addition, the simulation was rerun after every 100 repetitions, not only when there were a certain number of chargers in the station but up to a minimum of one and a maximum of four chargers. Firstly, the simulation is provided the total energy consumed by the station in a day as per a different number of charging units.

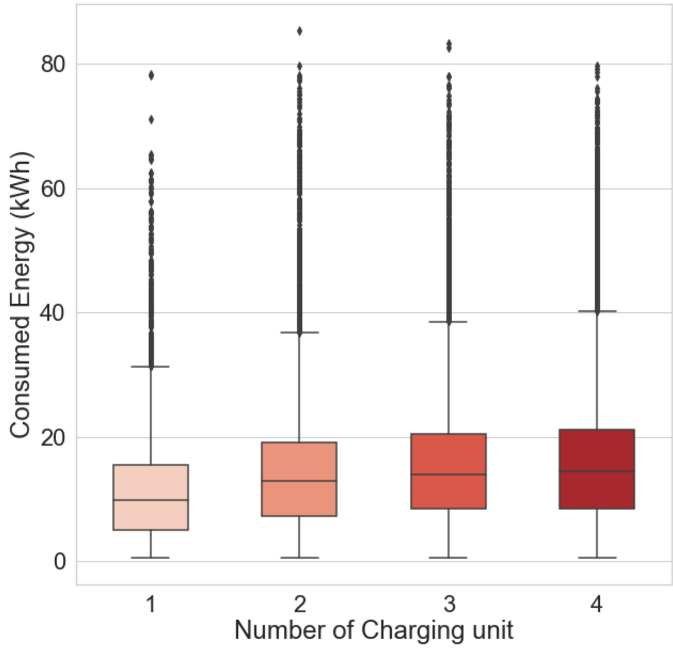


Figure 7: Energy Consumption as per Number of Charging Units for Case I

Figure 7 shows that the y-axis shows the energy consumed during the day, and the x-axis shows the number of charging units. Each charging unit has 22 kW AC, 24 kW DC and 50 kW DC charging sockets. An average of 400 vehicles come to the shopping center daily; between 60 and 100 vehicles utilize the EVCS. When there is a charging unit, the total energy consumed is less than two or more charging units. As shown in Figure 7, 50% of the results are between 10 kWh and 25 kWh on a vehicle basis, in the case of two or more charging units.

The charging time of the vehicles verifies the energy they consume as seen in Figure 8. Therefore, EVCS utilizes more users when there is only one charging unit or two or more charging units, as in the energy consumption graph depends on the vehicle. When energy consumption are analyzed daily, energy consumption varies depending on the number of charging units.

Figure 9 (a) shows energy consumption trend differences between different charging units in charging stations by 21:00. On the other hand, figures (c) and

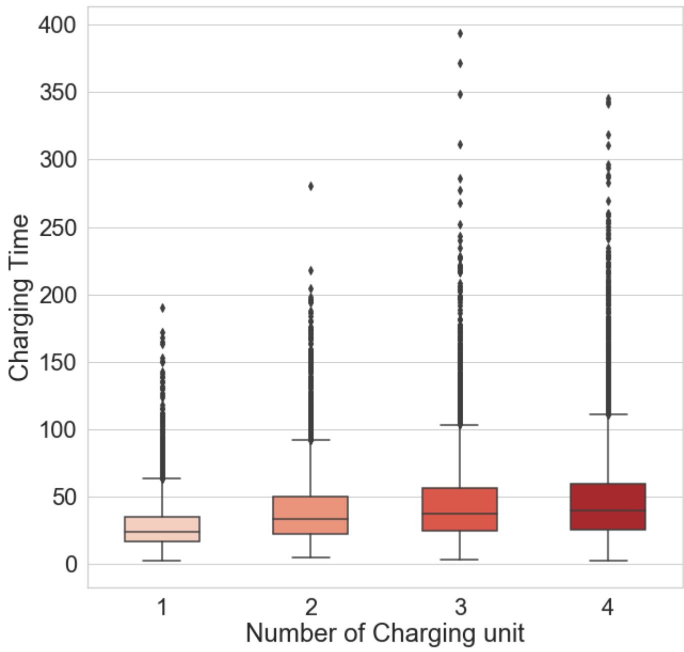
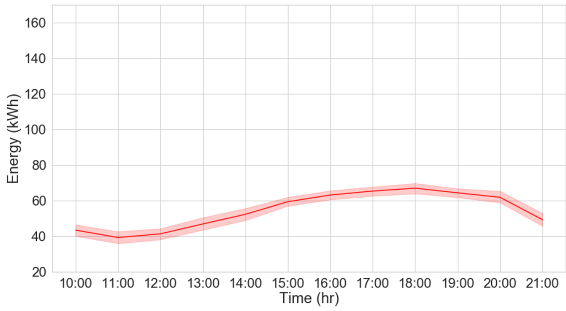
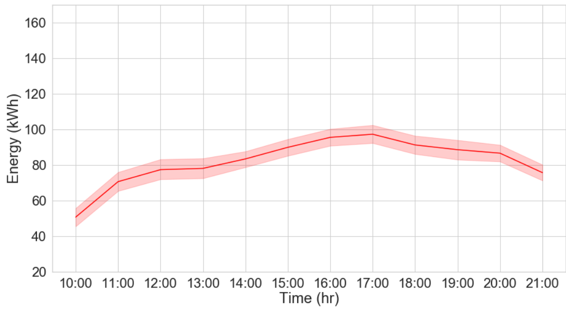


Figure 8: Charging Time as per Number of Charging Units for Case I

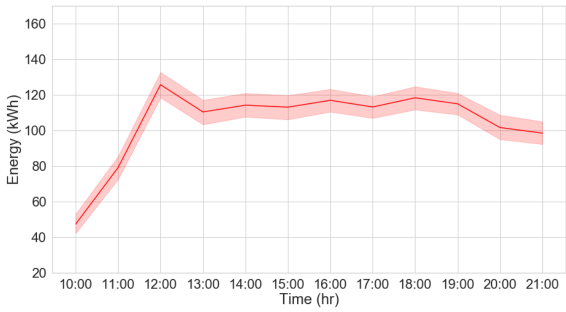
(d) have high similarities. In the light of the graphs above, there is an increase for the other EVCS except the ECVS with a charger unit between 10:00 and 12:00 to hourly energy consumption. If it has four charging units, the EVCS will consume the highest hourly energy of 180 kWh. There are eight different EV vehicle brands used in the simulation. Each of these vehicles has various battery capacities and charging sockets preferences. In addition, the probability parameters of generating vehicles for the simulation were recorded in the vehicle feature module. However, the amount of energy provided by vehicles from EVCS is not directly proportional to the probability of the vehicle being produced.



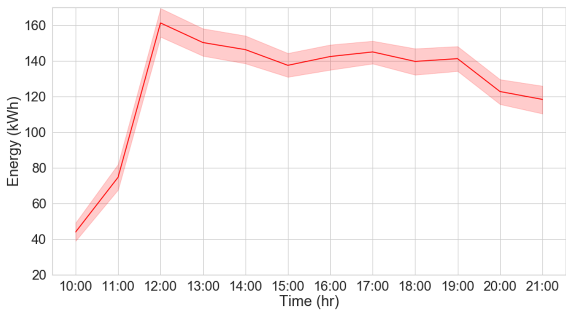
(a) One Charging Unit



(b) Two Charging Unit



(c) Three Charging Unit



(d) Four Charging Unit

Figure 9: Hourly Energy Consumption for Case I

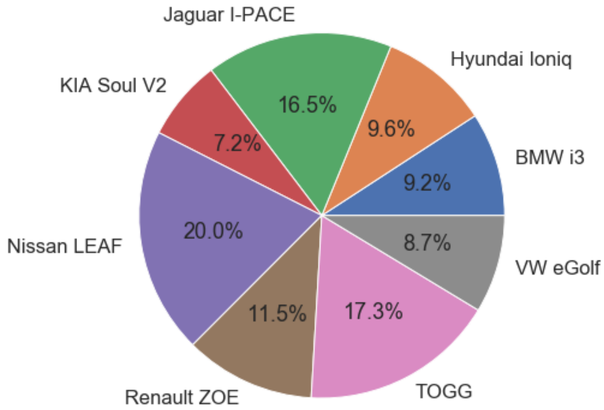
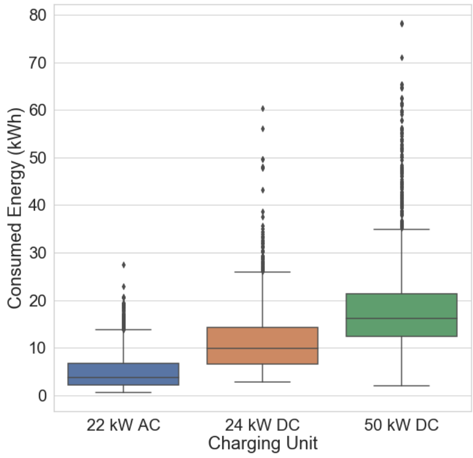


Figure 10: Energy Consumption Based on EV Brand for Case I

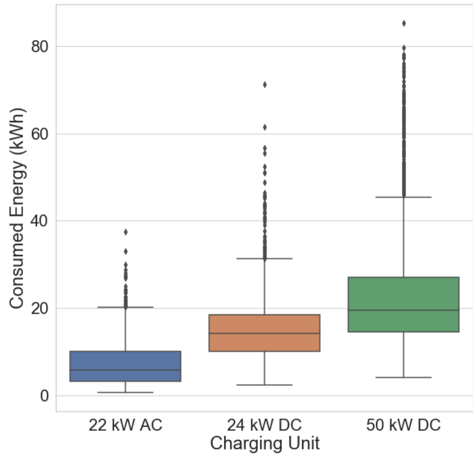
Nissan Leaf, Jaguar I-Pace vs TOGG are the brands that fulfill the most energy needs from EVCS. As seen in Figure 10, Nissan leaf ranks first in energy consumption for EVCS with 20%. Therefore, it is the most preferred BEV brand in Turkey. The critical point here is that although Jaguar I-Pace and TOGG are less likely to be preferred because their vehicle prices are higher than others, they cover 34% of the energy consumed.

Figure 11 shows that as the number of charging units increases, the amount of energy consumed by the charging station will increase. In addition, with the increase in the number of charging units, the difference between the lower and upper limit of the boxplot grew.

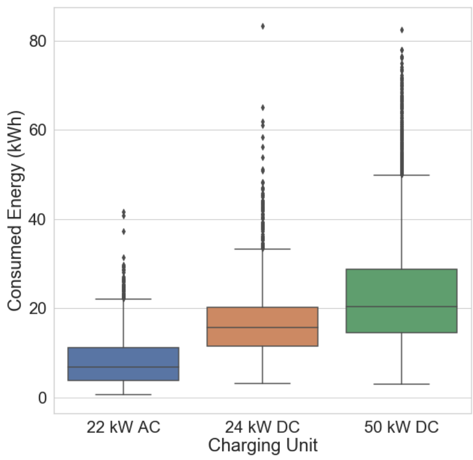
The load profile was created by running the simulation 100 times for a given day at the different number of charging stations which is sufficient for getting the possible scenarios. In addition, the power analysis is helpful for the avoid power losses and transformer overloads that might cause economic and electrical problems for the EVCS. In this case, EVCS is located in the shopping mall, so EVCS start to work at 08.00 am then closes at 10.00 pm. Therefore the load profile covers 12 hours a day; hence instantaneous power consumption is taken by



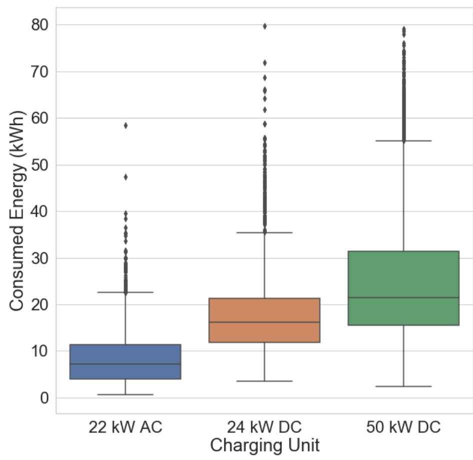
(a) One Charging Unit



(b) Two Charging Unit

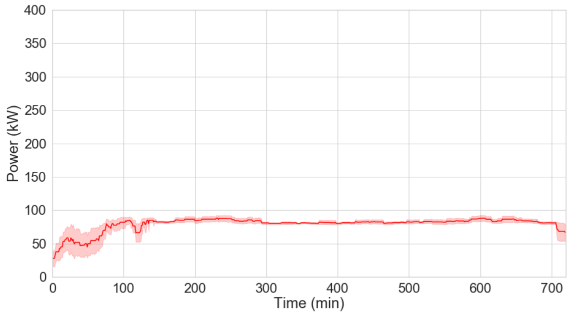


(c) Three Charging Unit

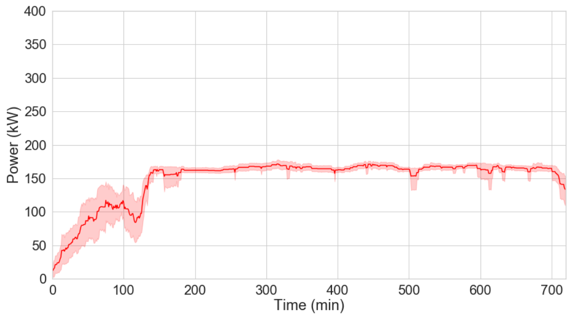


(d) Four Charging Unit

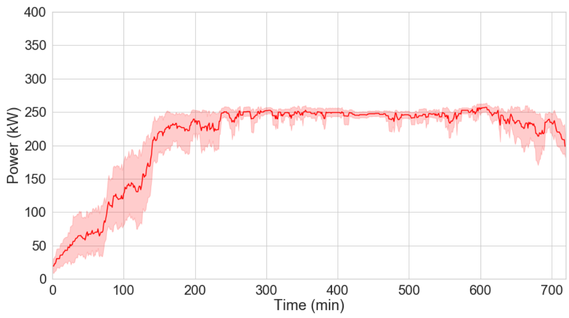
Figure 11: Energy Consumption as per Number of Charging Units for Case I



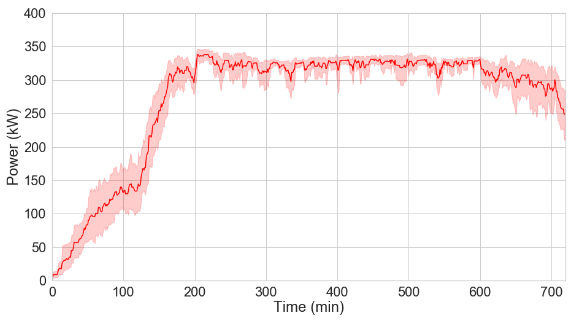
(a) One Charging Unit



(b) Two Charging Unit



(c) Three Charging Unit



(d) Four Charging Unit

Figure 12: Instantaneous Power Consumption as per Number of Charges for Case I

a minute base as shown in Figure 12. The result for the one charging unit is shown in Figure 12 (a). After 10 am, the power demand was mainly observed above 80 kW until the mall's closing time. The highest power demand is 96 kW with one charging unit. On the other hand, an unstable situation is observed before 10 am because the probability of customers coming to the shopping center is lower than the hours after hours. Figure 12 (b) shows that when two charging stations are installed in the EVCS, the daily power requirement usually varies between 150-175 kW after 10 am. The highest power level is 192 kW for two charging units. The power demand result in Figure 12 (c) is different than the previous ones. There is a regular rise in power demand until 10 am because EVs coming to EVCS can easily find a charging unit, and all vehicles can access their charging priorities. The highest power demand is 277 kW for three charging units.

4.2 Case II: (Highway) Rest Area

The rest area is located in between İstanbul to İzmir highway. The primary purpose of the second case is to observe the difference against Case I. There are different scenarios to simulate EVCS as one to four charging units. The number of customers coming to EVCS varies depending on the number of charging units in the station. About 400 vehicles arrive at the station daily, most of which use the rest area or the parking area. The number of EV owners using the daily charging station is an average of 47 vehicles for a single charging unit. If the capacity of the charging unit doubles, the number of EV vehicles arriving for charging will not double, contrary to the expectation, and an average of 65 electric vehicles will be charged daily. In the case of three and four charging units in the EVCS, the average number of charging vehicles are 78 and 95 vehicles. Minimum charging time is set to twenty-five minutes because EV owners traveling between cities do not want to charge less than twenty-five minutes. The average parking duration is 66 minutes, and the initial SoC average is 28%. The mean of provided energy is 20 kWh for each EV. Figure 13 shows that the amount of energy per vehicle depending on the number of charging units that is observed that the increase in the number of charging units is not effective in the amount of energy provided by the vehicles from EVCS.

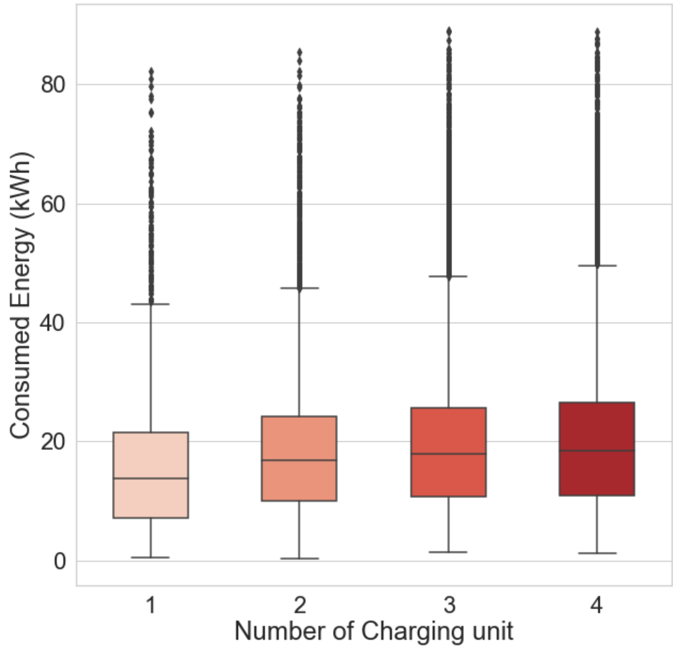


Figure 13: Energy Consumption as per Number of Charging Units for Case II.

Figure 14 demonstrates that each vehicle arriving at the EVCS shows the charging times range. It has been observed that the duration of stay in charge does not change depending on the number of charging units. For instance, in the case of 3 and 4 charging units, the EV charging time is almost the same. Figure 15 illustrates the consumed energy as per the charging unit monitored hourly. This is the essential metric of EVCS that is not only for tracking energy but also crucial for financial analysis. The energy consumption decreases as the EVCS approaches the closing time. When the number of charging units increases, energy consumption is reached the peak level earlier. The energy consumption trend encloses similarities with the EVCS established in the shopping centers popularity trend. The energy consumption per vehicle is important for financial calculations.

The power of the transformer in the region where the EVCS is located is vital

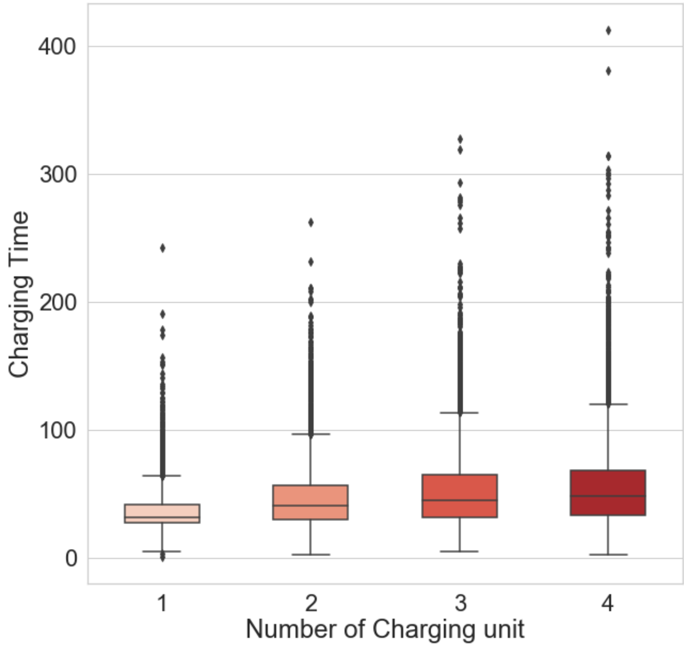
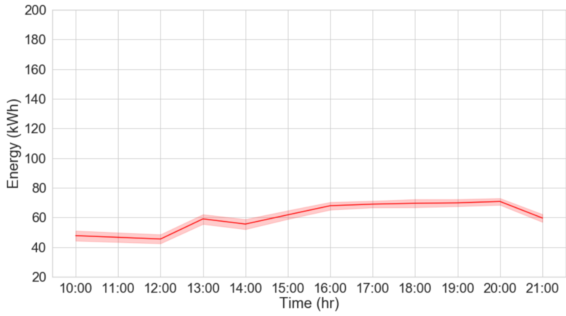
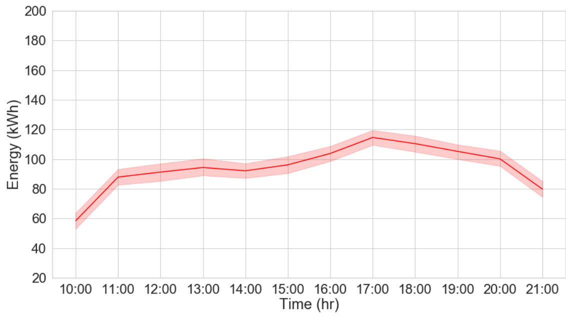


Figure 14: Charging Time as per Number of Charging Units for Case II

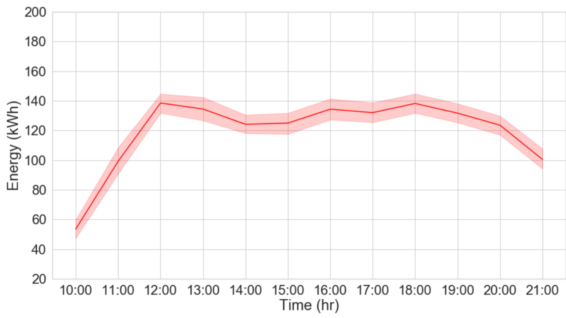
for the operation because if the demanded power cannot be supplied from the transformer in the region, electricity losses or power outages may occur. These losses result in loss of money and respect for the business, as well as loss of money for the customer. In this study, the station will analyze how much power is demanded per minute, not power losses or power quality. Figure 16 shows minute-based power demands in a day from one charger to four chargers. In graph (a), the power demand varies according to the confidence interval graph until noon because the probability of vehicle arrival at the station during these hours is low. EVCS demanded a maximum of 96 kW of power in one day, which means that the transformer at the station must be a three-phase transformer of at least 100 kVA. On the other hand, if a 100 kVA transformer is installed at the station, if another charging unit is wanted to be added to the EVCS, the station will not be able to serve the vehicles coming to be charged. As seen in graph (b), the power demand of the station is mostly between 150-175 kW. The power demand is more stable during peak hours than during fewer visitor hours. This is because



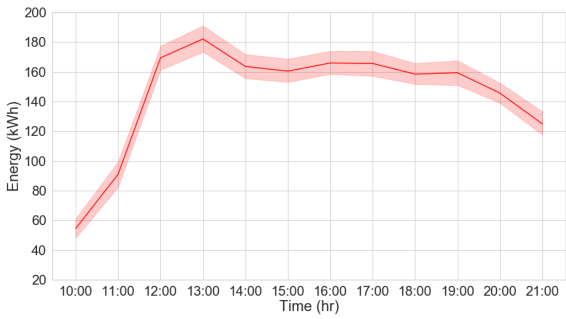
(a) One Charging Unit



(b) Two Charging Unit

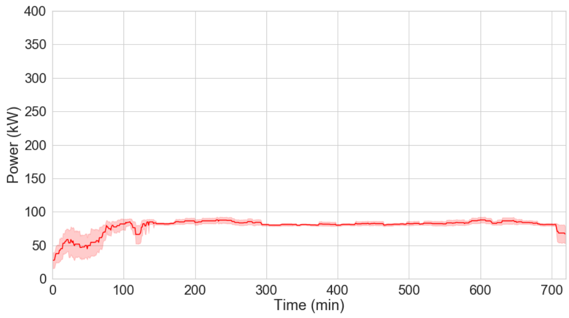


(c) Three Charging Unit

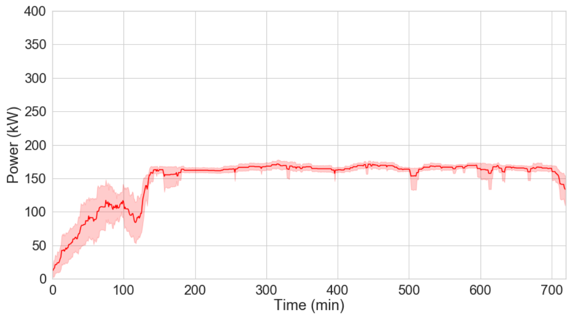


(d) Four Charging Unit

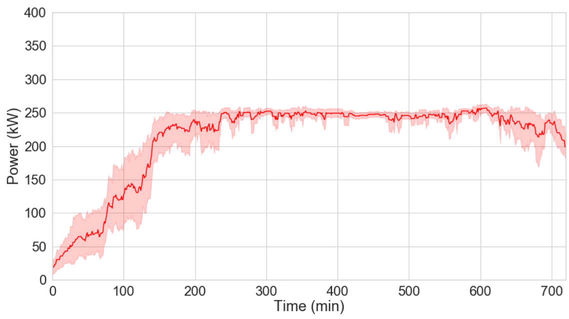
Figure 15: Hourly Energy Consumption Energy for Case II



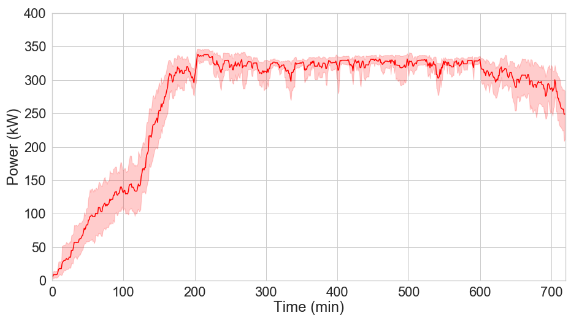
(a) One Charging Unit



(b) Two Charging Unit



(c) Three Charging Unit



(d) Four Charging Unit

Figure 16: Instantaneous Power Consumption as per Number of Charges for Case II

charging unit utilization is high during peak hours. For example, if four charging units are installed in the EVCS, the highest power demand will be 362 kW. To sum up, transformer selection should be made according to the number of charging units installed in the EVCS. The number of charging units should be determined according to the transformer.

CHAPTER V

FINANCIAL ANALYSIS

The interest of individuals in EVs is increasing, so the demand for charging stations will increase; however, investors have to make financial analyses and electrical analyses for the newly established EVCS. There are many different business models for EVCSs. The business model, in this case, the EVCS will be set up in the parking lot of a frequently visited shopping center in the city. One of the essential points for an investment to succeed is not to make an unnecessary investment, so it should analyze the number and type of charging units installed in the charging station.

5.1 Case I: (Downtown) Shopping Mall

In this case, financial analysis has been made for EVCS, which will be established for a famous shopping center in the Asian continent in Istanbul. In the financial analysis, land rent or park rent were not considered as the EVCS is owned by the landlord. Equipment maintenance costs or depreciation costs are not taken into account.

Electricity spent in kWh was taken into account as an expense, and EV owners' using parking lots with charging units were taken into account as income.Figure 18 shows that the y-axis shows the profit rates obtained from the vehicles, and the x-axis shows the type of charging socket. The highest profit percentage earned from a vehicle for a charging unit is 97%, lowest profit is 18%, with an average of 63% profit being acquired with a single charging unit. Therefore, the daily electricity cost of EVCS is approximately 800 TL, the money paid to EV owners, that is, the daily income that EVCS will obtain is around 2200 TL.

Figure 18 (b) illustrates the profit rates by two charging units. The box plots upper and lower bounds sizes are different such as the orange one shows the 24 kW

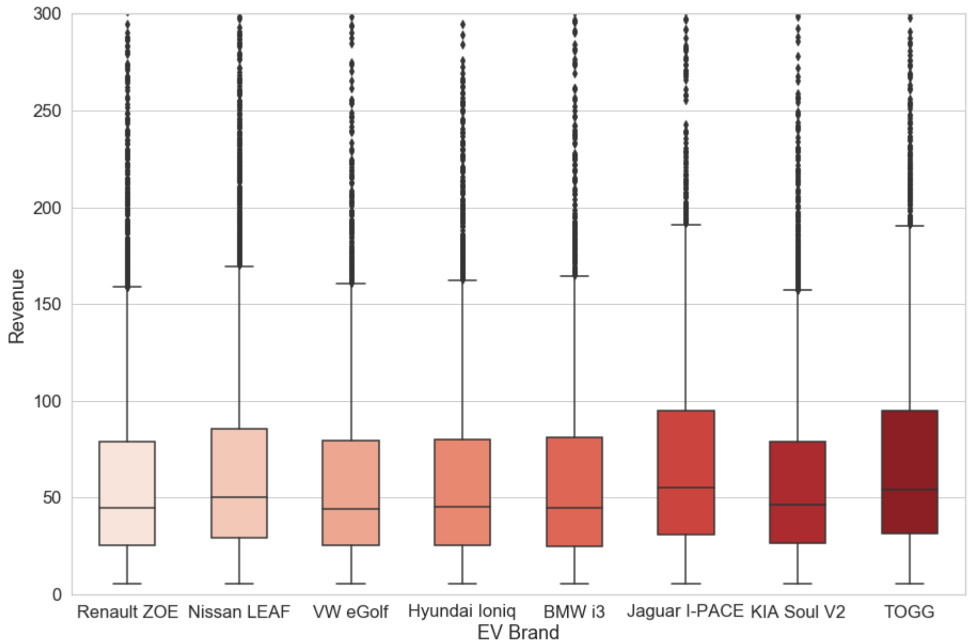


Figure 17: Electricity Cost as per EV based on Number of Charging Units

DC charging socket most of the profit rates into between 55% to 70% although, 50 kW DC, which is the green box, have profit rates between 40% to 80%. The highest profit rate is 97%, minıimum profit rate is 18% for each EV. The average of the daily cost of electricity is 1260 TL to provide service to EV owners; on the other hand, EVCS is earned around 4160 TL for each day. Consequently, the average total profit rate is 70% for 100 times simulation. In Figure 18 (c), the profit rates gained depending on the charging socket are given when there are three charging units in total. Although the average profit rate is 72%, the highest profit rate of a vehicle is 98%, and the lowest profit rate is 18%. The average daily income is 5870 TL, and expenses are 1630 TL. As the charging unit increases, the income rate obtained from the charging units increases compared to the previous ones. Figure 18 (d) is similar to (c) in terms of the profit rate, and there is no significant difference between the rates. However, there are differences in terms of profit obtained and expenses spent; when analyzed in terms of the profit rate, there is only a 1 percent increase compared to (c). The maximum and minimum

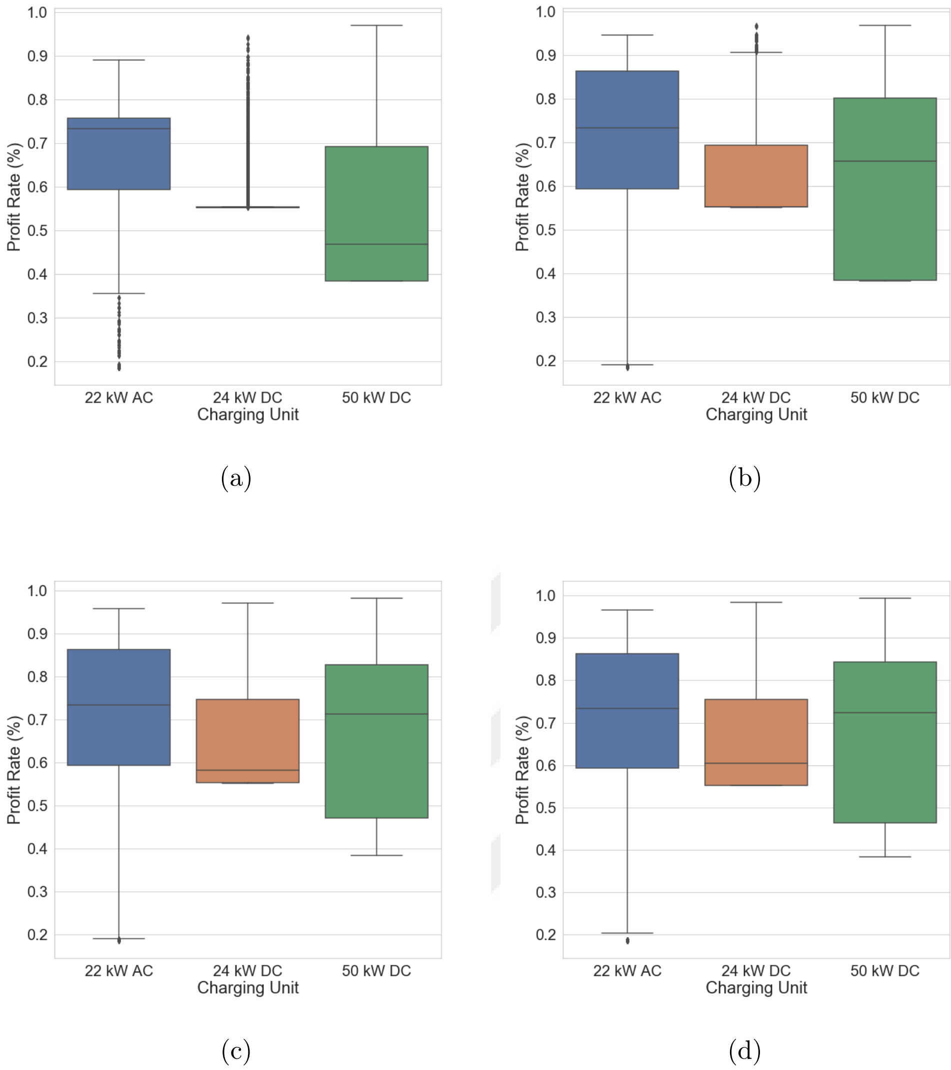


Figure 18: Profit Rates Depends on the Number of Charging Units for Case I

gain or expense for a single-vehicle does not change.

5.2 *Case II: (Highway) Rest Area*

The parking area used in Case II now serves as a rest area; this station is visited by people traveling between cities. In this Case II, expenses such as rent, depreciation, and initial installation are not analyzed as Case I; only the electricity usage fee and the fees that the customers will pay for using the charging units will be calculated. Losses are not considered when calculating the amount that EVCS will pay for electricity use, such as power losses. When Case 2 is analyzed as the income to be earned per vehicle, the average income is around 60 TL for vehicles using 50 kW DC per vehicle, 50 TL for 22 kW DC, and 30 TL for AC. Figure 19 illustrates the average revenues for each vehicle. TOGG and Jaguar I-Pace are the most profitable vehicles for EVCS because their priority is the 50 kW DC charger.

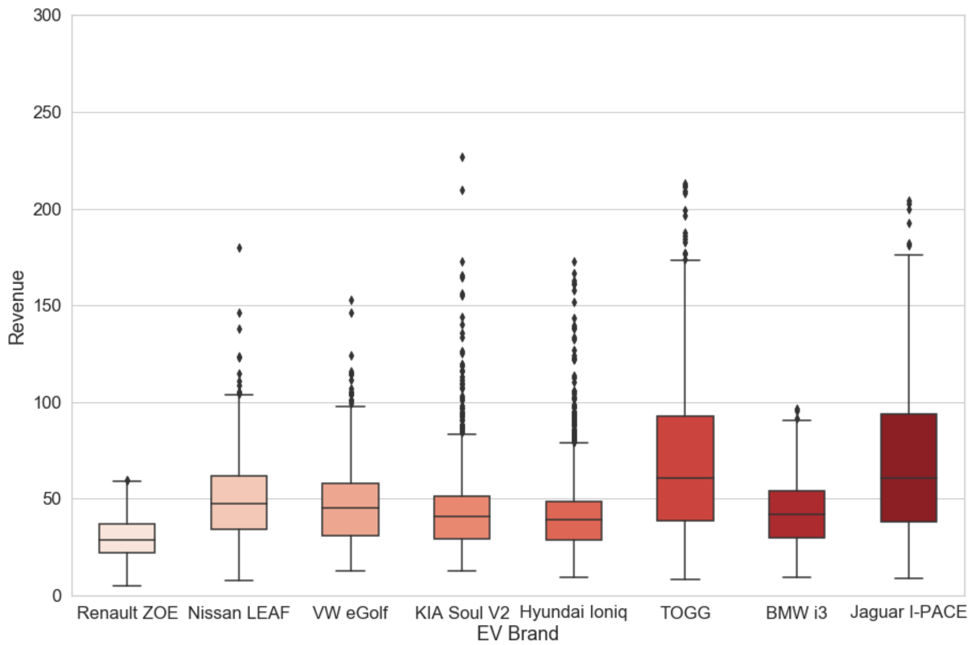


Figure 19: Electricity Cost as per EV based on Number of Charging Units

Figure 20 shows that the rate of income that can be obtained from 22 kW AC is much more profitable than other charging types. This profit rate varies between 60-90%. While calculating the profit of the EVs arriving at the EVCS station, the cost incurred for the electricity consumed divided by the amount that the electric vehicle will pay during the time it is parked is calculated, and this ratio is subtracted from one. The AC/DC converter inside the vehicle plays an essential role in creating such a difference according to other charging types. While the electrical power supplied from the DC charging stations is stable, the power drawn from the AC station depends on the converter.

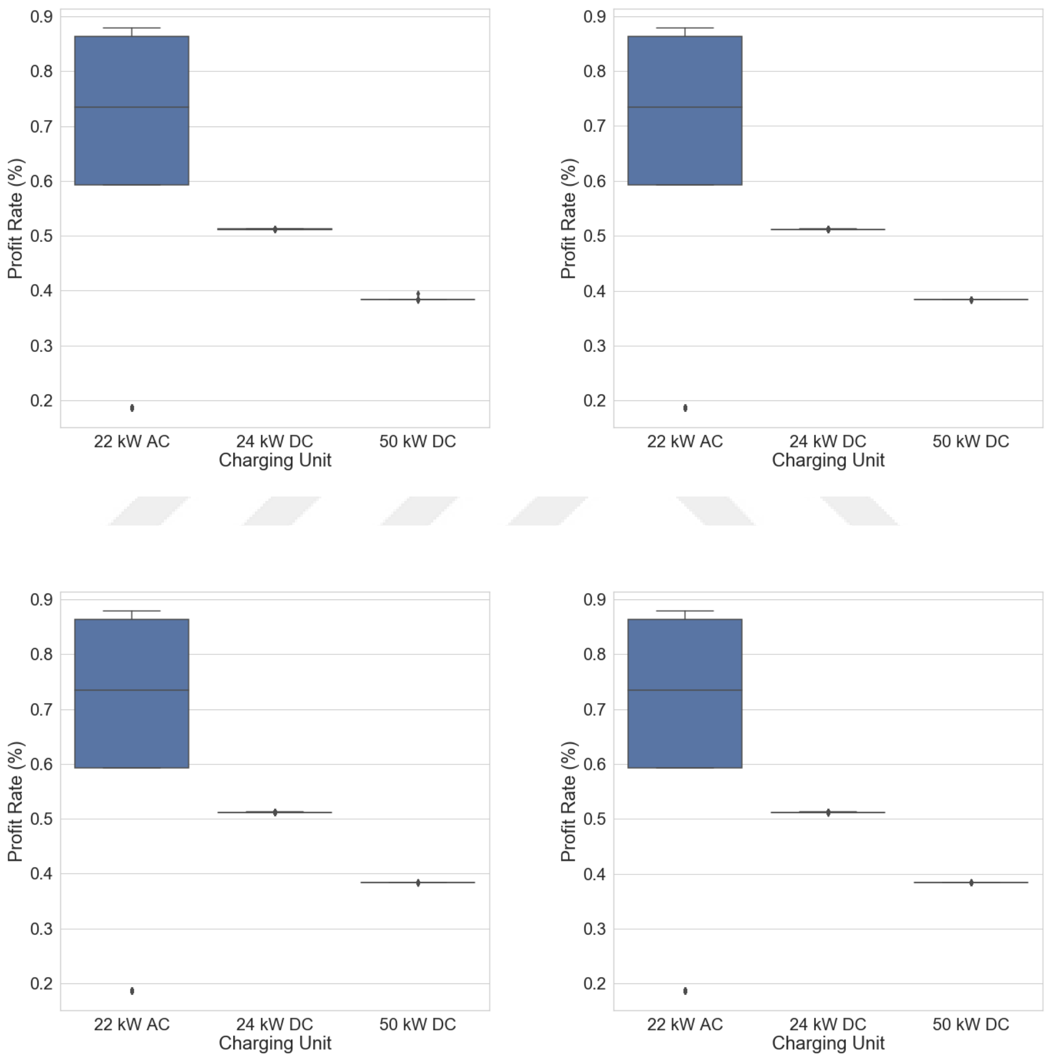


Figure 20: Profit Rates Depends on the Number of Charging Units for Case II

CHAPTER VI

FUTURE WORK

This thesis obtained the results by re-running the simulation for Case I & II, 100 times in each increment, from 1 charging unit to 4 charging units in total on a Sunday. More realistic forecasts should be made for the future by examining the simulation seasonally or annually, rather than one day to create data for future studies. In this thesis, the charging type of electric vehicles is assumed to be uni-directional mode; this means that charging flow has one direction which is the grid to EV battery, though it could be bi-directional. This allows the flow of energy from the vehicle to the grid (V2G) that system has many positive effects, such as avoiding the overload on the grid by controlling charging and discharging the battery [44]. Furthermore, it creates new opportunities by integrating the V2G system and renewable energy sources into a system such as energy trading [45]. As a result, EV owners can be transformed into a system that can make profit from an economic perspective. For example, suppose the vehicle is charged from renewable energy sources during the day and discharged from the vehicle to the grid during periods of high electricity consumption. In that case, the consumer will achieve financial earnings. On the other hand, V2G regulates frequency and voltage in the grid, provides peak shaving and load leveling [46]. To sum up, renewable energy sources, V2G or V2V studies can be added to the simulation. While applying a single model for the pricing strategy can be diversified, and many different models can be tried. E-Mobility data can be produced more realistically by conducting survey research for simulation.

CHAPTER VII

CONCLUSION

Consequently, the simulation was created to meet the need for the historical data set needed to meet the EVCS demand that arises with the rapidly growing number of EVs. While creating the simulation, some parameters were applied to the simulation beforehand, increasing its similarity to a real data set.These are the stations' popularity data from Google, the SoCs of the vehicles at the time they arrive at the station, the charging socket priorities of the vehicles, the minimum charging times connected to the station, and the fee to be paid per kWh to make financial calculations, and the prices that EV owners will pay depending on the charging socket per minute. The simulation has six different modules to create E-Mobility data set. The event generator has a dynamic probability density function to execute the real-life scenarios that generate events such as incoming or outgoing vehicles by tracking the time. For instance, the event generator does not generate departure events in the first minutes of the shopping mall. All events are registered in the registry book. In a day, approximately 400 vehicles have visited both EVCSs used in the simulation. Different results were obtained for the EVCS planned to be installed in Case I and II, for example, the average charge time of EVs is longer in Case II. Electrical analysis was performed in both ECVS, as a result of this analysis, the station in Case I reaches the peak point earlier than the station in Case II, but the power densities at the peak points are the same.

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