ISTANBUL TECHNICAL UNIVERSITY ★ ENERGY INSTITUTE

LIFE CYCLE ANALYSIS OF PV-ASSISTED CHARGING STATION

M.Sc. THESIS

Muhammed Cihat MERCAN

Energy Science and Technology Division

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JUNE 2018

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Thesis Advisor: Prof. Dr. Mehmet Özgür KAYALICA

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ ENERJİ ENSTİTÜSÜ

PV-DESTEKLİ ŞARJ İSTASYONUNUN MALİYET ANALİZİ

YÜKSEK LİSANS TEZİ

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HAZİRAN 2018

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Date of Submission : 4 May 2018
Date of Defense : 8 June 2018

FOREWORD

I would like to express my appreciation and thanks for my advisor Mehmet Özgür Kayalıca and Gülgün Kayakutlu for their continuous support in this research. It has truly been an honour and privilege to complete my study under their supervisions.

May 2018 Muhammed Cihat MERCAN
(Energy Systems Engineer)

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ABBREVIATIONS

ABC : Artificial Bee Colonization
App : Appendix
St : Station
BCB : Battery Charging Behavior
BESS : Battery Energy Storage System
COE : Cost of Energy
DR : Demand Response
EV : Electric Vehicle
EVCS : Electric Vehicle Charging Station
EPDK : Energy Market Regulatory Authority
EU : European Union
FIT : Feed-In-Tariff
GHG : Green House Gas
HOMER : Hybrid Optimization of Multiple Energy Resources
ISPARK : İstanbul Municipality Company for Park Service
KBA : Germany Federal Motor Transport Authority
LDC : Local Distribution Company
LF : Load Flow
MPC : Model Predictive Control
MPPT : Maximum Power Point Tracker
NPC : Net Present Cost
O&M : Operation and Maintenance
PDF : Probability Density Function
PEV : Plug-in Electric Vehicle
PSO : Particle Swarm Optimization
PV : Photovoltaic
PVCS : Photovoltaic Assisted Charging Station
SAE : Society of Automotive Engineers
SLF : Stochastic Load Flow
SOC : State-Of-Charge
TOU : Time-Of-Use
TEIAS : Turkey Electricity Transmission Company
V2G : Vehicle-to-Grid

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LIST OF SYMBOLS

C_{bat}	: Initial battery storage cost (€)
C_{ini}	: Total initial investment (€)
C_{main}	: Maintenance cost of storage battery per kWh (€/kWh)
C_{PV}	: Initial PV module cost (€)
C_{sta}	: Initial station cost (€)
d	: Discount rate
D_t	: Total energy demand of vehicles that have SOC below %80 (kWh)
$E_{g2b}(t)$	: Energy purchased from grid and transferred to storage battery (kWh)
$E_{g2v}(t)$	: Energy purchased from grid and transferred to vehicles (kWh)
$E_{solar}(t)$	: PV array output (kW)
$E_{s2b}(t)$	: Energy produced from solar and transferred to storage battery (kWh)
$E_{s2g}(t)$	: Energy produced from solar and sold to the grid (kWh)
$E_{s2v}(t)$	: Energy produced from solar and transferred to vehicles (kWh)
$E_{v2b}(t)$	: Energy taken from vehicle and transferred to storage battery (kWh)
$E_{v2g}(t)$	: Energy taken from vehicle and sold to the grid (kWh)
$E_{v2v}(t)$	: Energy transferred between vehicles (kWh)
$E_{b2}(t)$	: Total energy discharged from storage battery (kWh)
$E_{g2}(t)$	: Total energy transferred from grid (kWh)
$E_{upper}(t)$	: Maximum energy can be purchased from grid (kWh)
EVS_t	: Total possible excess energy supply of vehicles that have SOC above %80 (kWh)
$E_{v2}(t)$	: Total energy discharged from vehicles (kWh)
$E_{2b}(t)$	: Total energy charged to storage battery (kWh)
$E_{2g}(t)$	: Total energy transferred to the grid (kWh)
$E_{2v}(t)$	: Total energy charged to the vehicles (kWh)
ε_{cha}	: Battery charging efficiency (%)
ε_{dis}	: Battery discharging efficiency (%)
$G_{buy}(t)$	: Energy purchase cost from grid (€)
$G_{dep}(t)$	: Battery depreciation cost for every cycle (€)
$G_{main}(t)$	: Maintenance cost of battery (€)
$G_{oper}(t)$	: Monthly operational cost of the station (€)
$G_{park}(t)$	: Parking fee revenue (€)
$G_{sell}(t)$	: Energy sale to the grid revenue (€)
$G_{serv}(t)$	: Charging service revenue (€)
I	: Provided current by charging station (A)
IN	: Yearly total income of station (€)
IRR	: Internal Rate of Return
k_{dep}	: Percentage of battery depreciation cost in initial cost (%)
k_{self}	: Battery self-discharge factor (%)
k_{temp}	: Temperature coefficient (%/$^{\circ}C$)
n	: Number of vehicles

N : Cycle number of the storage battery
N_{park} (t) : Number of vehicles stay parked at station
NPV : Net Present Value of Project
OM : Yearly total operation and maintenance cost of station (€)
OM : Yearly total expense of station (€)
Q_{bat} : Capacity of the storage battery (kWh)
Q_i : Battery capacity of the i^{th} vehicle (kWh)
P_{buy} (t) : Price of grid electricity (€/kWh)
P_{dis} (t) : Paid price to vehicle for discharging (€/kWh)
P_{park} (t) : Price of parking service for vehicles (€/h)
P_{sell} (t) : Price of selling electricity to grid (€/kWh)
P_{serv} (t) : Price of charging service to vehicles (€/kWh)
P_{STC} : Power output under standard test conditions (kW)
R_{PV} (t) : Solar radiation on PV array (W/ m^2)
R_{STC} : Solar radiation under standard test conditions (1000W/ m^2)
SOC_{bat} (t) : State-of-Charge of storage battery
SOC_i (t) : Battery State-of-Charge of the i^{th} vehicle
TAC : Total Annualized Cost
V : Voltage value of charging station (V)
x_n : n^{th} year increase ratio of income and expense
θ : PV depreciation factor

LIFE CYCLE ANALYSIS OF PV-ASSISTED CHARGING STATION

SUMMARY

Due to increasing population and technological developments, the demand for energy continues to increase in the developing countries. Strong rising trends have been also recorded in Turkey and Asian countries. In response to this demand, hydrocarbon-based fossil fuels have always had a larger share than other primary energy sources. This causes problems such as environmental pollution, high emissions and global warming. Transportation sector forms large portion of this problem. But electric vehicles can be a solution to this problem.

Increasing penetration of electric vehicles into daily transportation system can bring new opportunities not only to reduce environmental emissions and grid impacts but also more profit for vehicle owners and vehicle charging station owners. This study proposes a hybrid model of optimization for scheduling of a charging station using battery storage. Electric vehicle charging station offers bi-directional energy transfer both from grid to vehicle and from vehicle to grid.

Vehicle-to-Grid (V2G) technology enables the electricity stored in the batteries of electric cars to be made available to the grid at times of high demand. When demand is low vehicles can perform regular charging. With this technology EV drivers will have opportunity to earn money depending upon their contribution to grid. On the other hand, this storage capacity can be used by grid operators to balance peaks and troughs of energy demand and supply.

Because of environment friendly solution for the charging process of electric vehicles is one of the most important issues, the designed station is also intended to make use of solar energy source.

This model has an electric vehicle station with ten vehicle-size, an external storage battery, solar panels and grid connection. In the charging station part, the hourly power demands of the vehicles and the possible energy amounts that they could transfer to the other vehicle or network were calculated on an hourly basis. Hourly solar power production was also calculated. Then system checks the relation between EV demand, possible supply and solar power which is called operational scenarios. According to the operation scenarios, decisions such as electricity purchase from grid, storing excess energy in battery or transferring excess energy of vehicles from one to another are taken.

Then objective function and the basic technical and economic constraints and parameters of the four main parts of the system were established. As a result, a model that evaluates economic benefits to calculate potential operator revenue was developed with MATLAB.

Then, the states of these variables were studied according to scenarios. Two scenarios were created at this stage.

In the first part of the first scenario; the system was operated with the actual price and demand and market prices in accordance with the regulations in Turkey. In the second part, the conclusions that will arise when the prices fall below the European Union prices have been examined.

In the second scenario; price parameters affecting the system are calculated based on future prices. In this scenario; changes in market prices that occurred in Europe was examined and prices may occur in Turkey was added as an input to the system.

The results of two key case studies were compared to examine the impact on the system of changing prices such as different electricity sales prices, parking fees and charge service fees.

PV-DESTEKLİ ŞARJ İSTASYONUN MALİYET ANALİZİ

ÖZET

Artan nüfus ve teknolojik gelişmeler nedeniyle enerji talebi gelişmekte olan ülkelerde artış göstermeye devam ediyor. Güçlü yükseliş trendleri de Türkiye ve Asya ülkelerinde kaydediliyor. Bu talebin karşılanmasında hidrokarbon bazlı fosil yakıtlar her zaman diğer birincil enerji kaynaklarından daha büyük bir paya sahip olmuşlardır. Bu durum da çevre kirliliği, yüksek emisyon ve küresel ısınma gibi sorunların ortaya çıkmasına neden olmaktadır. Ulaştırma sektörü de bu oluşan durumun büyük bölümünü oluşturmaktadır. Günlük hayatımızda kullandığımız araçların neredeyse tamamı içten yanmalı motorlar ile kimyasal enerjiyi hareket enerjsine çevirir. Bu durum da hava ve gürültü kirliliğinin yanında zararlı gazların doğaya salınmasına sebep olur. Ancak elektrikli araçlar bu soruna bir çözüm olabilir.

Elektrikli araçlar; doğası gereği düşük direkt emisyon değerine sahiptir. Çalışmaları daha sessizdir ve içlerinde bulunan elektrik motoru çok yüksek bir verimle çalışır. Tekerleklere iletilen mekanik güç; konvansiyonel araçlardaki gibi fosil yakıttan değil, günümüzde erişim olanağı yüksek olan elektrik gücünden karşılanır.

Bunların yanında sonlu fosil yakıtlar, potansiyel petrol krizleri ve bu durumların uluslarası alanda ortaya çıkardığı siyasi anlaşmazlıklar, bu kaynaklara olan ilgi ve yatırımların daha çevreye duyarlı olan yenilebilir enerji kaynaklarına kaymasını sağlamaktadır.

Güneş ve rüzgar gibi mevcut yenilenebilir enerji kaynakların süreksiz bir yapıda olmaları, büyük ölçekte enerji üretim olanakları için yüksek maliyet gerektirmeleri, emre amadelikleri yani anlık ihtiyaç anında kısa sürede talebi karşılama kapasitelerinin düşük olmaları, bu kaynaklar için dezavantaj olarak gözüküyor. Bu sebeple son yıllarda genelde bu kaynakların mevcut sistemlere entegre edilerek diğer enerji kaynakları ile hibrit bir yapı oluşturmaları sağlandı.

Elektrikli araçların günlük ulaşım sistemine katılımının artırılması, sadece çevresel emisyonları ve şebeke etkilerini azaltmak için değil, aynı zamanda araç sahipleri ve araç şarj istasyonu sahipleri için daha fazla kar sağlamak için yeni fırsatlar getirebilir.

Bu çalışmada da elektrikli araçların şarj işlemi için çevre dostu çözüm, en önemli konulardan biri olduğu için, tasarlanan istasyon da şebeke bağlantısının yanında güneş enerjisi kaynağını kullanacak şekilde tasarlanmıştır.

Bu alanda son yıllarda, hem istasyon operatörü kısmında hem de elektrikli araç sahipliği kısmında maliyetleri minimize etme veya karın maksimize edilmesi amacıyla bir çok farklı şehir ve araç verisi ile bir çok çalışma ortaya konuldu. Bu çalışmada da İstanbul'da öngörülen halka açık bir şarj istasyonun kullanım ömrü boyunca oluşacak gelir, gider ve net bugünkü değerleri incelenerek operator açısından karın maksimize edilmesi amaçlandı.

Bahsedilen elektrikli araç şarj istasyonu; harici depolama bataryası da içererek şarj istasyonunun planlanması için hibrid bir optimizasyon modeli önermektedir. Bu araç şarj istasyonu, hem şebekeden araca hem de araçtan şebekeye iki yönlü enerji transferi sağlar.

Bu teknoloji, Vehicle-to-Grid (Araçtan-Şebekeye), V2G teknolojisi, elektrikli araçların akülerinde depolanan elektriğin yüksek talep anında şebekeye verilebilmesini sağlar. Talep düşük olduğunda araçlar normal şarj yapabilirler. Bu teknoloji ile EV sürücüleri şebekeye katkılarına bağlı olarak para kazanma fırsatına sahip olurlar. Diğer taraftan, bu depolama kapasitesi, şebeke operatörleri tarafından enerji talebi ve arzını dengelemek için kullanılabilir.

Elektrikli araçların şarj işlemi için çevre dostu çözüm, en önemli konulardan biri olduğu için, tasarlanan istasyon da güneş enerjisi kaynağını kullanacak şekilde tasarlanmıştır.

Bu modelde on araç kapasiteli bir elektrikli araç istasyonu, harici bir depolama bataryası, güneş panelleri ve şebeke bağlantısı bulunmakta. Şarj istasyonu kısmında; öncelikle Türkiye'deki şarj istasyonu kurulum ve işletmesi yapan E-şarj firmasından elektrikli araçların ortalama şarjlanma süreleri, şarj istasyonu güç değerleri, araçların batarya kapasiteleri ve istasyondaki araçların mevcut şarj seviyeleri ile temel bir veri seti oluşturuldu. Daha sonra bu veriler ile araçların saatlik güç talepleri ve diğer araç veya şebekeye aktarabilecekleri muhtemel enerji miktarları saatlik olarak hesaplandı. Aynı adımda; istasyonu kurulu olduğu öngörülen konum için ortalama saatlik ışınım ve hava sıcaklığı değerleri ile saatlik güneş enerjisi üretimi de ayrıca hesaplandı.

Bir sonraki operasyonel senaryo adımında sistem; elektrikli araçların saatlik güç talebi, olası arz kapasitesi ve güneş enerjisinden üretilen güç arasındaki ilişkiyi kontrol ederek, bu şartlar altında şebekeden elektrik alımı, bataryada fazla enerjinin depolanması veya araçların fazla enerjisinin birinden diğerine aktarılması gibi kararları alır.

Bu aşamada sistemde talep fazla olduğunda; gerekli enerji şebekeden veya harici bataryadan sağlanabilir. Aynı şekilde araçlardan deşarj edilebilecek enerji miktarında göre arz fazlası yaşandığında, bu enerji anlık elektrik fiyatına ve harici batarya kapasitesine göre şebekeye satılabilir veya depo edilebilir. Ayrıca elektrik fiyatı düşükse ekstra enerji şebekeden satın alınıp takip eden saatlerde oluşabilecek muhtemel talep için depo edilebilir.

Sistemde temel olarak dört ana bileşen bulunur. Bunlar elektrikli araçların bulunduğu şarj istasyonu, elektrik şebekesi, güneş enerjisini elektrik enerjisine çeviren güneş panelleri ve harici depo amaçlı batarya. Daha sonra sistem içindeki dört ana kısmın temel teknik ve ekonomik kısıt ve parametreleri oluşturuldu. Sonuç olarak potansiyel operatör gelirini hesaplayabilmek için ekonomik faydaları değerlendiren bir model MATLAB ile geliştirildi.

Daha sonra bu değişkenlerin birbirleri olan durumu farklı senaryolara göre incelendi. Bu aşamada iki adet senaryo oluşturuldu.

Birinci senaryonun ilk kısmında; Türkiye'deki yönetmelik ve piyasa fiyatlarına uygun bir şekilde gerçek fiyat ve talep ile sistem çalıştırıldı. İkinci kısımda ise fiyatların Avrupa Birliği fiyatlarının altına düştüğü durumda oluşacak sonuçlar incelendi.

İkinci senaryoda; sisteme etki eden fiyat parametreleri gelecekte oluşabilecek fiyatlar üzerinden hesaplandı. Bu senaryoda; daha önce Avrupa örneğinde oluşan piyasa fiyatlarının zaman içerisinde değişimi incelenerek, Türkiye'de oluşabilecek fiyatlar sisteme girdi olarak eklendi.

İki senaryonun sonuçları karşılaştırılarak farklı elektrik satış fiyatları, park ücretleri ve şarj servis ücretleri gibi fiyatlarının değişiminin sistem üzerindeki etkileri incelenmiştir.

1. INTRODUCTION

1.1 Motivation

Global warming threatens our earth. Due to increasing population and technological advancements energy consumption goes up day by day. World still needs fossil fuel to meet its needs. And it is clearly known that this process causes greenhouse gases to be emitted. Excessive increase of these gases damages our earth. This is a problem of transportation sector at the same time. 76% of total CO2 emissions comes from road transport [1]. Now 98.8% of total cars work with conventional fuel and this situation drives us to an environmental disaster. Therefore, some steps must be taken to change the course of events. With the help of technology use of renewable sources became widespread and that presents us an alternative solution.

Electric vehicles were developed to change this situation. These vehicles despite Internal Combustion Engine (ICE) vehicles have an electric motor and battery kit. They are more robust and require less maintenance. Since the widespread acceptance of EVs usage rates are increasing each year. According to International Energy Agency Report 750.000 EVs were sold in year 2016 [2]. These vehicles should be fueled by electric via charging stations which can be done also through our homes, private or public charging stations. With development of this technology total number of publicly accessible charging stations surpassed 330.000 unit all over the world.

These stations can not only transmit energy to vehicles but also to produce environment friendly solar energy, to store energy for vehicles and to provide frequency regulation by feeding grid in times of need. Thus, air quality of cities will increase, usage of fossil fuels will decrease and money that spent on fuels will be utilized for public welfare.

This study is about an electric vehicle charge station. This station has connection to grid and allows to flow energy from vehicle to grid (V2G) and grid to vehicle. This concept is supported with external storage battery and solar panels. According to demand of vehicle's need, electricity prices and storage battery condition, charging station will buy energy when electricity prices are lower and sell energy when electricity prices are higher.

In the literature, there are some studies about storing electricity in external batteries to buy and sell electricity to grid according to prices. And there are also studies on electric vehicle charge station design. Some commercial applications of these stations are also available mostly in USA and Europe.

In our case PV-assisted charging station will be optimized with objective of maximization of operator’s income. And due to working system of station such as deciding whether charging or discharging storage battery and whether selling or buying electricity from grid, Mixed-Integer Optimization Model that includes binary system will be used.

Objective function and other system constraints which may be useful for this study will be stated at Mathematical Modelling section.

1.2 Background

High penetration of EVs into the electricity market is expected in the near future, and with their complex charging behavior, their charging load models need be investigated. In order to investigate operational profit of EVCS some uncertain factors which affect charging behavior should be taken into consideration. Several earlier studies have considered modelling of EV charging demand considering uncertainty.

In a study [3], possible power demand of two charging station is estimated based on Markov-Chain traffic model and teleportation approach. Arrival rates of vehicles were calculated based on average trip duration, turning ratio of vehicles and average velocity. Then two hours of durations from morning, afternoon and evening are chosen. SOC of vehicles estimated between 0.2 and 0.3 with PDF. It is considered in both stations that there are two different charging station charger capacity of 50 kW and 120 kW. 90% with 120 kW charger. According to created scenarios vehicles will be charged fully or charged partially with different charger rating equipment. As result, charging demand varies according to different charging sequence.

In another study [4], profitability of a PVCS is assessed with four main parameters of service quality, economic benefit, environmental benefit and grid effect. Then these parameters are also divided in their own sections such as renewable share, yearly net profit, PVCS effect on energy obtained from grid etc. Parking durations and arrival times of vehicles are estimated with PDF and daily driving distances of vehicles calculated with a survey. With objective function of self-consumption of PV modules and meeting vehicles' charging demand, one-year effectiveness analysis is assessed in two scenarios with actual data.

In another study [5], a PVCS with V2G technology is designed and built. Also, fast and high efficient MPPT system is used in this 24 kW station. Solar panels produce more energy than needed and sells excess energy to grid. In a cloudy day PVCS is supported by grid between 5-10 am. Since this interval has generally low energy consumption rate this situation also balances extra load supply of the grid. It is also stated that between 20-23 hours EV batteries can be discharged and energy can be transferred to grid thus load demand can be balanced.

In another study [6], energy management of a PVCS is realized with offline optimization, online learning and Rule-based decision making. Daily data measured as offline from vehicles is used in online learning. And Rule-based method and online learning creates a real-time algorithm. When electricity prices are lower online learning algorithm stores daily weather, driving conditions etc. data and when electricity prices are higher Rule-based algorithm decides whether to charge or not. Objective function of offline optimization is to maximize the daily profit and since the problem is discrete and non-linear, PSO method is used. With nine month of irradiation data and vehicle arrival and departure data 200 kW PV system is designed and different effect of different optimization methods were examined.

In another study [7], an optimal charging strategy is developed. Simulation is done for China and for 32640 EV with Dijkstra's road planning optimization which assigns weights to the roads used. Charging strategy that is done with multi-objective programming decreases traffic congestion and increases vehicle velocity while increasing offset values of node voltages and decreasing power losses at the same time.

In another study [8], cost analysis of EV charging station is performed based on environmental emission, economics and performance. Six scenarios which include on-grid and off-grid and also diesel generator, PV and BESS and both of these components are considered. Data for EVs are taken from Drive4Data foundation in Ontario. Inputs such as EV load demand, radiation data and component costs are given to HOMER program and optimum size of components and energy plan is obtained as output. System calculates minimum cost according to six different scenarios.

In another study [9], uncertainties such as domestic load type, EV charger rating, charging times and charging durations are modelled with probabilistic approach. Effects on distribution transformer, cable loading and voltage and power losses are evaluated according to variation of uncertainties. Two different EV penetration level are tested with data taken by England Ministry of Transportation.

In another study [10], maximizing of vehicle owners' profit through frequency regulation stated with considering LMP (Local Marginal Price), RMCP (Regional Marginal Price) and SOC variables. According to different SOC, charge and discharge ratings different numbers of charging sequence combination is found for same EV plug-in duration. These combinations increase when plug-in durations increase thus minimum and maximum profit results are obtained.

In another study [11], an aggregator that provides frequency regulation is designed. Aggregator manages energy transfer between EV and grid with its own algorithm therefore acts as an EMS (Energy Management System). Three variables of aggregator are charging sequence, charging time and charger rating. A profit function and its constraints are defined and a simulator which works with dynamic programming is formed.

In another study [12], sizing of on-grid PV-biomass system with objective of annual cost minimization is done by comparing ABC (Artificial Bee Colonization) and HOMER. A mathematical model is designed for PV module, biomass gasifier, inverter and grid. Model is simulated with pre-defined operation strategy and as result ABC algorithm gives better results than HOMER.

In another study [13], EV fleet includes 100 taxis in Shenzen region of China is evaluated according to total cost, cost of energy and carbon emissions with four different scenarios. EV load demand is predicted and inserted into HOMER. PV-battery-EV scenario has the highest cost of energy while having the least emission per kWh.

In another study [14], a method which calculates EV performance and compares it with ICEs (Internal Combustion Engine) in a multi-objective optimization problem with providing the cheapest charging and minimizing the emissions is proposed. Mixed-Integer Bi-Criteria model that evaluates different levels of EV penetration is used with real data obtained from TEIAS.

2. LITERATURE REVIEW

2.1 Electric Vehicles

An electric vehicle, uses one or more electric motors or traction motors for propulsion. An electric vehicle may be powered through a collector system by electricity from off-vehicle sources, or may be self-contained with a battery, solar panels or an electric generator to convert fuel to electricity [15].

There are two main types of electric vehicles that are used in daily life.

2.1.1 Plug-in hybrid electric vehicles

Plug-in Hybrid Electric Vehicles (PHEVs) are electric vehicles contain batteries which can be charged by plugging them into an electrical outlet. These vehicles also have an on-board internal combustion engine that may charge batteries through a generator. PHEVs use about 40 to 60 percent less petroleum than conventional vehicles [16]. Examples of PHEVs are Mitsubishi Outlander, Opel Ampera, Volkswagen Golf GTE and BMW i8.

2.1.2 Battery electric vehicles

A battery electric vehicle (BEV) is a type of electric vehicle that uses chemical energy stored in rechargeable battery packs. There is no internal combustion engine or fuel tank. Battery electric vehicle must be plugged in to get required energy to drive and its range is limited by its battery pack. Since there is no combustion engine there is no direct emission of battery electric vehicle. Examples of BEVs are Nissan Leaf, Tesla Model S, BMW i3 and Renault Zoe.

2.2 Electric Vehicle Market

Abundance of EVs rise year by year in the most part of the world. Europe is one of the presider area in this market. According to ‘Electric Vehicles in Europe’ report of European Environment Agency, around 700 BEVs were sold across the EU in 2010.

In 2013 when range of plug-in hybrid models increased and became significantly more popular more than 49 000 EVs of which 50 percent were BEVs sold in European region. Latest 2015 data shows that around 150 000 EVs were purchased by customers. And almost 40 % percent of EVs were battery electric vehicles [17].

The EU Commission wants to reduce carbon dioxide emissions by 30 percent from cars by 2030 [18]. And Germany is preparing this type of radical change in its excessive automobile sector. As of January 2018, about 25,000 all-electric and 130,000 hybrids cars were registered on German roads. On the other hand, 14.5 million diesels and 30 million gasoline cars were registered, according to the KBA vehicle registration authority [19].

And every new produced vehicle in Germany should be emission free by 2030 in order to meet pollution reduction goals [19].

Globally, the number of global electric cars have surpassed 2 million in 2017 after passing 1 million trains in 2016 [20].

2.3 Charging Station and Charging Techniques

An electric vehicle charging station also called EV charging station, is an element in an infrastructure that supplies electric energy for the recharging of electric vehicles, such as plug-in electric vehicles, battery electric vehicles, and plug-in hybrids [16].

There are two charging options for an electric vehicle; AC and DC charging.

AC is alternating current which is available on power grid. It is transmitted from generation plant to consumption point in this form. When power reaches to EV, it is converted by vehicle to DC to store it in battery. AC charging is the most common method of charging due to its lower costs thus being cheaper charging option for drivers. This method is suitable for parking spots where vehicle will be parked more than 20 minutes such as home, workplace and parking lot charging.

DC is direct current which is available on charging station when it is converted by station itself. This charging method has high installation and operation costs thus is a more expensive option for EV drivers. DC charging offers much faster charging which allows quick recharge during long-distance trips. This method is suitable for on the go charging such as highways.

According to SAE standards, charging equipment are classified into three main levels. Level 1, Level 2 and Level 3. Usually Level 1 and Level 2 are used for AC charging and Level 3 is used for DC charging.

Level 1 (AC) or also called as Opportunity Charger supports up to 120 volts single phase AC, 16 amps, and 1.9 kW charging rate. Generally, ampere rate is limited to 20 amps.

Level 2 (AC) or also called as Normal Charger supports up to 240 volts single phase AC, 80 amps, and 19.2 kW charging rate.

Level 3 (AC) or also called Fast Charger supports up to 43 kW charging rate. Generally, ampere rate is limited to 100 amps. Even though there is a classification called Level 3, usually Level 3 phrase refers to DC Fast Charge. DC Fast Charge (DCFC) or DC Quick Charge (DCQC) or Supercharger describes the fast charging stations. And Level 3 can be splitted into three parts. DC Level 1, DC Level 2 and DC Level 3.

DC Level 1 supports up to 200-450 volts DC, 80 amps and 36 kW.

DC Level 2 supports up to 200-450 volts DC, 200 amps and 90 kW.

DC Level 3 supports up to 200-600 volts DC, 400 amps and 240 kW.

It can be seen from Figure 2.1 that Level 1 and Level 2 are AC chargers and Level 3 is DC chargers [21].

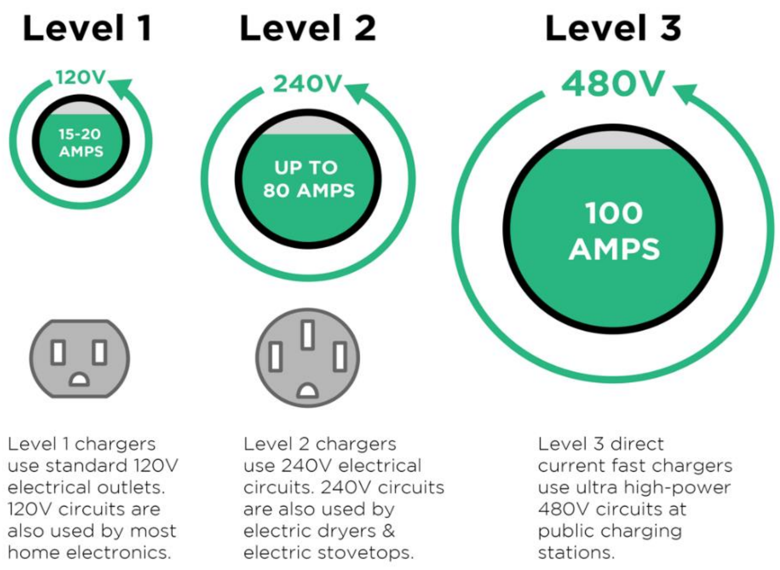

Figure 2.1 : Basic comparison of main charging levels.

There are main charging protocols that is used for charging electric vehicles.

CHAdeMO is a DC charging protocol and enables charging up to 150 kW. There are about 350 members, 50 charger manufacturers and 230 certified chargers under this e-mobility collaboration platform. Automobile manufactures that support CHAdeMO include: Nissan, Mitsubishi, Subaru, Toyota.

SAE Combo or The Combined Charging System (CCS) is a quick charging method for electric vehicles with DC charging protocol up to 350 kW. Automobile manufactures that support Combined Charging System include: BMW, Volkswagen, General Motors, Audi, Ford and Mercedes, Ford.

Tesla Supercharger network is a system of 480-volt DC fast-charging stations enables charging up to 120 kW and built by Tesla Inc. to serve company's manufactured all-electric vehicles.

IONITY is the joint venture of BMW Group, Daimler AG, Ford Motor Company and the Volkswagen Group with Audi and Porsche [22]. Company was established to build charging stations across Europe. These stations will be open to public usage and allow fast charging with capacity up to 350 kW.

It can be said that depending upon conditions there are three charging behavior for EVs.

Charging at home, requires standard residential electric supply and a 3.5 kW charger which charges an average small car in 8 hours. For example, it takes 16 hours for a Tesla Model S to make full charge with that outlet.

Charging on the go, offers EV charging all over the city with different charger ratings. For example, when it takes 75 minutes for a Tesla Model S to make full charge with a 120 kW Tesla Supercharger it varies with very common 22 kW and 50 kW outlets that can be found all over the world.

Charging at work, which may include standard residential outlet or equipment with different power ratings give opportunity to workers to charge their parked vehicles while they work and to operator to use parked vehicles for vehicle-to-grid purpose with the help of charging system which allows bi-directional energy transfer that was developed by Japanese motor company Honda [23] or Dutch EV charging station company New Motion [24].

According to survey [20] 63% of PHEV charging was done at home, 16% at work and 21% at public locations. And same survey shows that 55% of PHEV charging was done at home, 15% at work and 30% at public locations.

Total number of publicly accessible charging stations surpassed 330.000 unit all over the world. And in Turkey there are nearly 400 charging points in public places and total 1500 charging points when houses and personal ones are included.

2.4 Solar Energy in City Use

According to analysis published by Sandbag [25] electricity generation by solar, wind and biomass in Europe rose by 12 % and surpassed coal based generation for the first time with 679 terawatt hour energy in 2017. Electricity production from coal was 669 terawatt hours.

According to Turkey Ministry of Energy and Natural Resources, by the end of July 2017, electricity generation percentages were 34% natural gas, 31% coal, 24% hydraulic power, 6% wind, 2% geothermal energy and 3% other sources [26].

Renewable energy transition moves beyond traditional city energy landscape, from buildings to transport, to industry and power. Great benefits can be provided to cities such as better living spaces and cleaner air. It means integrating energy supply and demand across the board, through smart technologies, rigorous planning and holistic decision-making.

In addition, cities are vital for the world's low carbon economy transition. This amounts to 65% of global energy use and 70% of man-made carbon emissions [27].

According to [28], more than 90% of people living in urban areas, cope with air quality levels exceeding the World Health Organization limits.

In April 2016, San Francisco became the first major US city to require all new buildings to install rooftop solar PV. The rule builds on a California requirement for new buildings to set aside 15% of the roof area to be “solar ready” [29].

The City of Adelaide has launched a solar leasing initiative to reduce the upfront cost of installing solar systems, targeted at lower income households [30].

Tokyo city is planning to install 1 GW of rooftop systems by 2024, including 22 MW of PV on metropolis-owned buildings and facilities by 2020. City aims for increasing the share of renewables to 20% of total power generation by the time of the Summer Olympics in 2020 [31].

Penetration of renewable energy sources into distribution systems are gradually being recognized as important alternatives and has been attracting the attention of policy makers and researchers because of their friendliness to the environment and potential to reduce dependence on fossil fuels [32].

Environmental emissions and high fossil fuel costs are an important motivation to increase the penetration of solar PV in power generation. Incentives, positive state policies and support mechanisms have made this source the fastest growing alternative energy source [33].

With V2G technology effective usage of renewable energy can be increased. Inherently electric vehicles can soak up the solar power when solar output is high and can return power to grid thus reduce evening ramp-up.

2.5 V2G System with Storage and PV Panels

Vehicle-to-Grid (V2G) technology enables the EV to both charge and discharge electricity back to the grid. This is done by using a special type of charge point capable of AC / DC power conversion and the discharge functionality of the car. Both the direction and speed of the charging power can be remotely controlled. The main difference of V2G in comparison to regular smart charging (‘V1G’, unidirectional, from grid to EV) is the discharge functionality. By having the option to discharge it is possible to avoid a situation where the full battery limit is reached and the car just sits there idle. This creates a significant increase in flexibility per EV and a better integration with the local grid.

This delivery of grid services supports the overall adoption of renewable energy sources such as solar and wind. Since these are intermittent and thus more volatile than traditional energy resources (such as gas-fired power plants) they need to be complemented with backup capacity. V2G power control effectively turns an EV into a stationary battery, which can provide this service during the time the EV is parked and connected to the charge point. By aggregating or pooling together multiple EVs we can create a 'virtual battery' which can deliver these grid services on a larger, nationwide scale.

Components of Vehicle-to-Grid system can be seen in Figure 2.2 below.

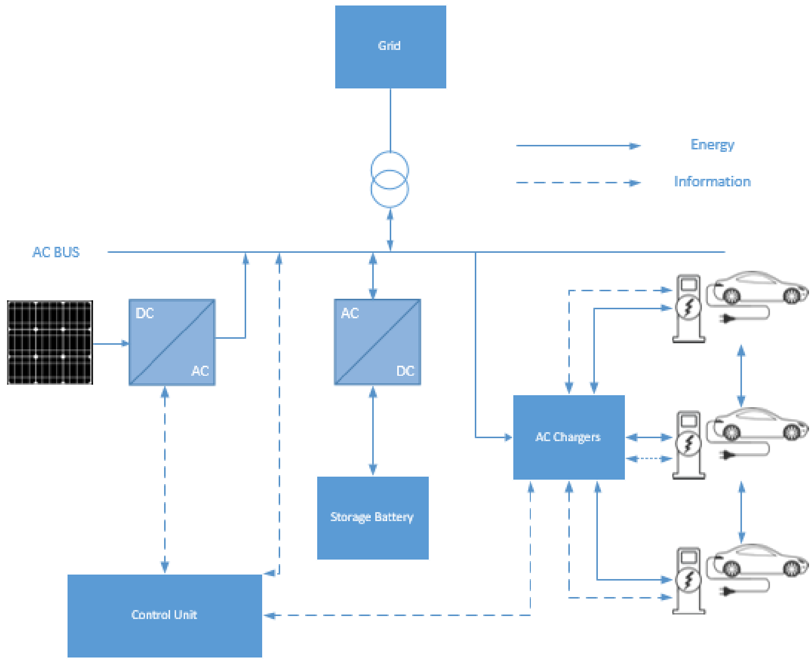

Figure 2.2 : General overview of Vehicle-to-Grid system.

V2G system also has ancillary services such as operating reserve, peak shaving and frequency regulation stated below.

In the case of an electricity network, a generator failure or a shortage of supply, the demand must be met again in a short time. In such a case, the production capacity that the system operator can use in a short time is called the operating reserve.

Peak shaving is the process of reducing the amount of energy purchased from the utility company during peak demand hours.

The result of the intermittent power generation made from renewable energy sources is the frequency deviation in the network. In this case, the energy storage system will charge or discharge depending on the increase and decrease of the grid frequency. Thus, the network frequency remains within the specified limits.

V2G technology enables the electricity stored in the batteries of electric cars to be made available to the grid at times of high demand [24]. When demand is low vehicles can perform regular charging. With this technology EV drivers will have opportunity to earn money depending upon their contribution to grid. On the other hand, this storage capacity can be used by grid operators to balance peaks and troughs of energy demand and supply.

NewMotion, Dutch EV charging company has installed the world's first public charging points which can transfer electricity both to vehicles and to grid by using Vehicle to Grid (V2G) technology. The company launched the pilot in Amsterdam alongside grid company Alliander, technology company Enervalis and innovation platform Amsterdam Smart City.

3. METHODOLOGY & MODEL

3.1 Mixed Integer Programming

An integer programming problem is a mathematical optimization or feasibility program in which some or all of the variables are restricted to be integers. In many settings, the term refers to integer linear programming (ILP), in which the objective function and the constraints (other than the integer constraints) are linear [34].

Mixed-Integer Programming is a special case of 0-1 integer linear programming, and in this programming unknowns are binary and the constraints must be satisfied.

Decision variables must be either 1 or 0. Such variables are called binary variables and are used to model yes/no decisions. With this method, a decision can be made about building a power plant or buying a product. But these integer variables make a problem non-convex, and therefore more difficult to solve. When more integer variables are added solution and memory time will rise exponentially.

An important special case is a decision variable that must be either 0 or 1 at the solution. Such variables are called 0-1 or binary integer variables and can be used to model yes/no decisions, such as whether to build a plant or buy a piece of equipment. However, integer variables make an optimization problem non-convex, and therefore far more difficult to solve. Memory and solution time may rise exponentially as you add more integer variables.

When integer variables are used different types of problems can be defined and solved. Mixed Integer Programming is used in scheduling, production planning and telecommunication networks.

In order to solve constrained optimization problem;

Main inputs such as; a set of variables, an objective function and a set of constraints should be given.

Best solution for the objective function in the set of solution that satisfy the constraints such as equations, inequalities which can be linear or non-linear.

A linear mixed-integer linear programming problem is stated in Equation 3.1 [34].

$$\begin{aligned} &\min cx \\ &\text{subject to } Ax \leq b \\ &\text{where } x \in Z^n x R^p \end{aligned} \tag{3.1}$$

In this case objective function and all constraints are linear and some variables are integers, some variables are continuous.

3.2 Problem Statement

In our work, we present an electric vehicle charging station with ten vehicles. The vehicle owners leave their vehicles at this station at the time they want, and then take their vehicles as a full battery. In the meantime, it is not necessary to transfer only one-way energy to the vehicles in the parking lot. This means that the vehicle can be both charged and discharged. This presents different opportunities for the station operator and vehicle owners. The operator can discharge vehicles to a level and can transfer the energy to the vehicles with which the demand is being made. It can also store this energy in an external battery. Or it can use the energy generated from the solar panels to meet the demand and the energy from the grid at the same time.

In addition, according to the current purchase price of electricity from the grid, it can supply all the needs of the vehicles from the external battery.

Variations like this can also happen when charging the car. In our system, the operator decides the conditions that will occur depending on the different price and system parameters.

In our problem, a charging station model with ten vehicles is put forward first. On an hourly basis, the presence of each vehicle on this station, the SOC values and the battery capacities are generated in accordance with the source of the data received. On this EV Demand and Supply Side section, hourly demand and possible supply quantities are determined according to SOC values of existing vehicles. At the same time, the amount of supply generated as a result of solar power generation is also determined.

Then relation between the EV demand, the possible EV supply and the solar supply are examined in accordance with the rules set out in the Operational Flowchart section. These rules determine how energy transfers in the system will be made in case of demand or supply is surplus.

In the next section, Operational Scenarios, the relation between the previously mentioned EV demand, the possible EV supply and the solar power supply will show how energy transfers will be done as a result. The three main operational scenarios show how much transfer to the storage battery, network and vehicles, in some cases extra purchases from the network, and how these changes with hourly energy prices.

Then all the indices, variables and parameters involved in the model will be explained alphabetically in the Nomenclature section. In the following section, the objective function of the system and its constraints will be described with explanations.

Then some assumptions are made for the technical capacity and economic value of the foreseen system.

Finally, two main case studies are being developed with goal of maximizing operator profit. First of; the system is operated with the actual price and demand and market prices in accordance with the regulations in Turkey. Second case study; if the prices fall below the prices of the European Union.

The results of two key case studies are compared to examine the impact of changes in prices, such as different electricity sales prices, parking fees and charge service fees, on the system.

3.3 Proposed Model for Charging Electric Vehicles

3.3.1 EV demand and supply side

Basic parking lot scheme is stated in Figure 3.1 below.

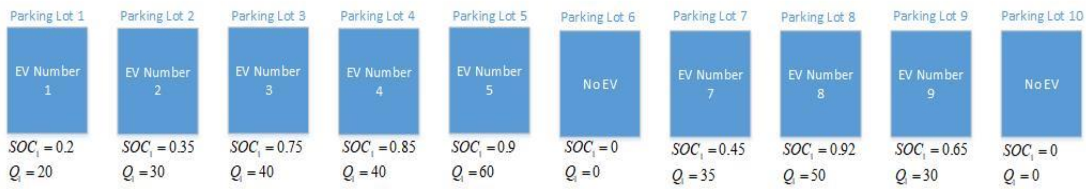

Figure 3.1 : Parking lot scheme consisting of 10 EVs.

Where $\alpha_{i,t}$ is binary variable takes a value of '1' if the SOC value at the time t of the vehicle i^{th} is less than 80% and $\beta_{i,t}$ is also binary variable takes a value of '1' if the SOC value at the time t of the vehicle i^{th} is more than 80%. Both these variables were stated in Equation 3.2a and 3.2b. If $SOC_i(t)$ of i^{th} car is zero then $\alpha_{i,t}$ and $\beta_{i,t}$ values become zero. This means that there is no vehicle at i^{th} parking lot.

$$\alpha_{i,t} = \begin{cases} 1 & 0 \leq SOC_i(t) \leq 80 \\ 0 & \text{else} \end{cases} \quad (3.2a)$$

$$\beta_{i,t} = \begin{cases} 1 & SOC_i(t) > 80 \\ 0 & \text{else} \end{cases} \quad (3.2b)$$

Then, matrices $\alpha_{i,t}$ and $\beta_{i,t}$ form D_t and EVS_t which are hourly EV demand and possible excess EV energy supply, respectively. And $E_{solar}(t)$ is photovoltaic power generation at each time t. These three variables were stated in Equation 3.3a, 3.3b and 3.3c.

$$D_t = \sum_{t=1}^{24} \alpha_{i,t} VI \quad (3.3a)$$

$$EVS_t = \sum_{t=1}^{24} \beta_{i,t} VI \quad (3.3b)$$

$$E_{solar}(t) \leq P_{STC} * \theta * \frac{R_{PV}(t)}{R_{STC}} * \left[1 + k_{temp}(T_c(t) - T_{STC})\right] \quad (3.3c)$$

According to the relationship between these three basic variables, the system decides what to do. This is indicated in the following operational flowchart, Figure 3.2 below.

Managing energy transfer between PV modules, storage battery, electric vehicles and grid can be done via these rules which will eventually serve to reach general objective of the system. These rules form a characteristic regulation for each part of the system and they will be established in order to apply dispatch strategy.

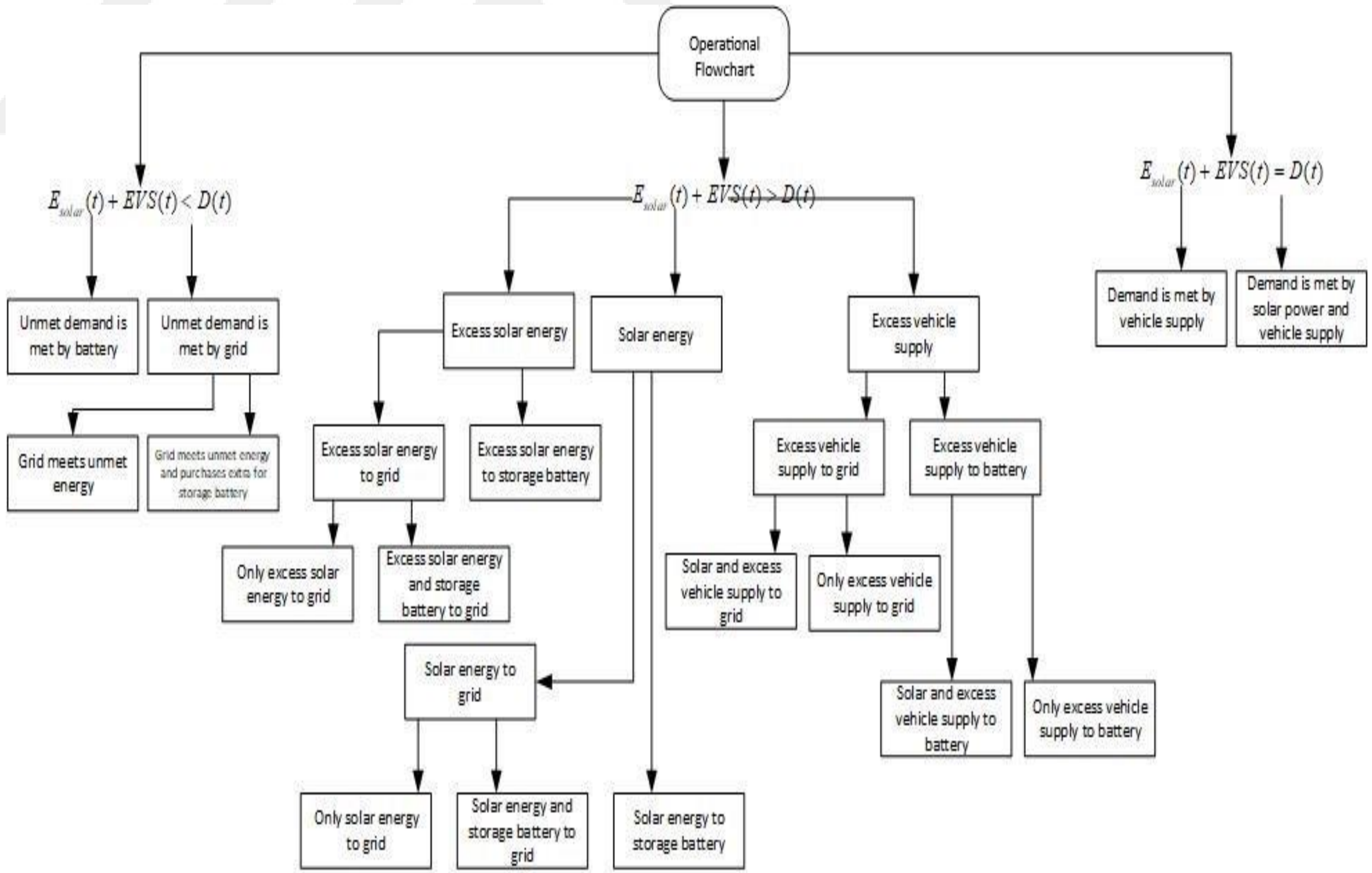

Figure 3.2 : Operational flowchart of the system

There are basically three scenarios in the operational flow chart section. These scenarios are based on the relationships between $E_{solar}(t)$, EVS_t and D_t. These scenarios decide whether the demand will be met from the grid or storage battery when there is too much power demand, or if the electricity sale price is cheap, what is to be done for excess supply. The sub-scenarios are also shown with detail in the flowchart.

These detailed sub-scenarios or also called operational scenarios will be described at operational scenarios below.

3.3.2 Operational scenarios

At time t;

In the first case, vehicle demand is higher than vehicle supply and solar power combined as shown in the Equation 3.4a.

$$E_{solar}(t) + EVS_t < D_t \tag{3.4a}$$

It means that produced solar energy and surplus vehicle energy will be used for system demand as shown in Equation 3.4b and Equation 3.4c. But still extra energy is needed. Then according to Equation 3.4d missing energy will be met either from grid purchase or storage battery discharge depending electricity purchase price and SOC of storage battery.

$$E_{solar}(t) = E_{s2v}(t) \tag{3.4b}$$

$$EVS_t = E_{v2v}(t) \tag{3.4c}$$

$$D_t - E_{solar}(t) - EVS_t = \begin{cases} E_{g2v}(t), & p_{buy} \leq a \ \&\& \ SOC_{bat}(t) > 20 \\ E_{g2v}(t), & p_{buy} \leq a \ \&\& \ SOC_{bat}(t) \leq 20 \\ E_{b2v}(t), & p_{buy} > a \ \&\& \ SOC_{bat}(t) > 20 \\ E_{g2v}(t), & p_{buy} > a \ \&\& \ SOC_{bat}(t) \leq 20 \end{cases} \tag{3.4d}$$

In this case, if system meets unmet demand by grid purchase according to Equation 3.4e it can also purchase extra energy for storage battery as in shown in Equation 3.4f. a value is stated in the assumption section that prepared for scenarios.

If;

$$p_{buy} \leq a \ \&\& \ SOC_{bat}(t) \leq 20 \tag{3.4e}$$

Then;

$$E_{g2b} = 5VI \tag{3.4f}$$

In the second case, vehicle demand equals to vehicle supply and solar power combined as shown in the Equation 3.5a.

$$E_{solar}(t) + EVS_t = D_t \tag{3.5a}$$

It means that there is no need for extra source.

- If vehicle demand is higher than vehicle supply;

Demand is met by solar power and vehicle supply together demand as shown in Equation 3.5b and Equation 3.5c.

$$E_{s2v}(t) = E_{solar}(t) \tag{3.5b}$$

$$E_{v2v}(t) = EVS_t(t) \tag{3.5c}$$

- If vehicle demand equals to vehicle supply;

Demand is met only by vehicle supply as shown in Equation 3.5d and Equation (3.5e).

$$E_{s2v}(t) = 0 \tag{3.5d}$$

$$E_{v2v}(t) = EVS_t(t) \tag{3.5e}$$

In the third case, vehicle demand is lower than vehicle supply and solar power combined as shown in the Equation 3.6a.

$$E_{solar}(t) + EVS_t > D_t \tag{3.6a}$$

It means that excess energy will be sold to grid or transferred to battery depending on electricity sale price.

In this case, when system sells or store surplus energy of solar generation and vehicle supply, system can also discharge and sell storage battery energy if storage battery SOC is high enough and electricity sell price is high.

- If vehicle demand is higher than vehicle supply;

Demand is met by solar power and vehicle supply together as shown in Equation 3.6b and Equation 3.6c. And excess solar energy is either sold to the grid or transferred to storage battery according to Equation 3.6d. Storage battery can also transfer energy to the grid depending electricity prices and its SOC as shown in Equation 3.6e and Equation 3.6f. b value is stated in the assumption section that prepared for scenarios.

$$E_{v2v}(t) = EVS_t \tag{3.6b}$$

$$E_{s2v}(t) = D_t - EVS_t \tag{3.6c}$$

$$E_{solar}(t) - E_{s2v}(t) = \begin{cases} E_{s2g}(t), & p_{sell} \geq b \ \&\& \ SOC_{bat}(t) \leq 80 \\ E_{s2g}(t), & p_{sell} \geq b \ \&\& \ SOC_{bat}(t) > 80 \\ E_{s2b}(t), & p_{sell} < b \ \&\& \ SOC_{bat}(t) \leq 80 \\ E_{s2g}(t), & p_{sell} < b \ \&\& \ SOC_{bat}(t) > 80 \end{cases} \tag{3.6d}$$

If;

$$p_{sell} \geq b \ \&\& \ SOC_{bat}(t) > 80 \tag{3.6e}$$

Then;

$$E_{b2g} = 5VI \tag{3.6f}$$

- If vehicle demand equals to vehicle supply;

Demand is met only by vehicle supply as shown in Equation 3.7a. And produced solar energy is either sold to the grid or transferred to storage battery according to Equation 3.7b. Storage battery can also transfer energy to the grid depending electricity prices and its SOC as shown in Equation 3.7c and Equation 3.7d. b value is stated in the assumption section that prepared for scenarios.

$$E_{v2v}(t) = EVS_t \tag{3.7a}$$

$$E_{solar}(t) = \begin{cases} E_{s2g}(t), & p_{sell} \geq b \ \&\& \ SOC_{bat}(t) \leq 80 \\ E_{s2g}(t), & p_{sell} \geq b \ \&\& \ SOC_{bat}(t) > 80 \\ E_{s2b}(t), & p_{sell} < b \ \&\& \ SOC_{bat}(t) \leq 80 \\ E_{s2g}(t), & p_{sell} < b \ \&\& \ SOC_{bat}(t) > 80 \end{cases} \tag{3.7b}$$

If;

$$p_{sell} \geq b \ \&\& \ SOC_{bat}(t) > 80 \tag{3.7c}$$

Then;

$$E_{b2g} = 5VI \tag{3.7d}$$

- If vehicle demand is lower than vehicle supply;

Demand is met only by vehicle supply as shown in Equation 3.8a. Excess vehicle supply and produced solar energy is either sold to the grid or transferred to storage battery according to Equation 3.8b and Equation 3.8c. Storage battery can also transfer energy to the grid depending electricity prices and its SOC as shown in Equation 3.8d and Equation 3.8e. b value is stated in the assumption section that prepared for scenarios.

$$E_{v2v}(t) = D_t \tag{3.8a}$$

$$EVS_t - E_{v2v}(t) = \begin{cases} E_{v2g}(t), & p_{sell} \geq b \ \&\& \ SOC_{bat}(t) \leq 80 \\ E_{v2g}(t), & p_{sell} \geq b \ \&\& \ SOC_{bat}(t) > 80 \\ E_{v2b}(t), & p_{sell} < b \ \&\& \ SOC_{bat}(t) \leq 80 \\ E_{v2g}(t), & p_{sell} < b \ \&\& \ SOC_{bat}(t) > 80 \end{cases} \tag{3.8b}$$

$$E_{solar} = \begin{cases} E_{s2g}(t), & p_{sell} \geq b \ \&\& \ SOC_{bat}(t) \leq 80 \\ E_{s2g}(t), & p_{sell} \geq b \ \&\& \ SOC_{bat}(t) > 80 \\ E_{s2b}(t), & p_{sell} < b \ \&\& \ SOC_{bat}(t) \leq 80 \\ E_{s2g}(t), & p_{sell} < b \ \&\& \ SOC_{bat}(t) > 80 \end{cases} \tag{3.8c}$$

If;

$$p_{sell} \geq b \ \&\& \ SOC_{bat}(t) > 80 \tag{3.8d}$$

Then;

$$E_{b2g} = 5VI \tag{3.8e}$$

3.3.3 Mathematical Model

Objective function of general mathematical model was stated in Equation 3.9 below.

$$\text{Max } Z = \sum_{n=1}^{25} \left[\frac{IN_n - OUT_n - OM_n}{(1+d)^n} \right] - C_{ini} \tag{3.9}$$

In EV constraints;

Equation 3.10a represents the satisfaction of EV demand is met by solar, grid and battery. Equation 3.10b represents total energy charged to vehicles comes from solar, battery or grid. Equation 3.10c represents total energy discharged from vehicles goes to other vehicles, battery or grid. Equation 3.10d represents SOC change after every time interval.

$$E_{s2v}(t) + E_{g2v}(t) + E_{b2v}(t) + E_{v2v}(t) = D_t \quad (3.10a)$$

$$E_{2v}(t) = E_{s2v}(t) + E_{g2v}(t) + E_{b2v}(t) + E_{v2v}(t) \quad (3.10b)$$

$$E_{v2}(t) = E_{v2g}(t) + E_{v2b}(t) + E_{v2v}(t) \quad (3.10c)$$

$$SOC_i(t+1) = SOC_i(t) + \frac{E_{2v}(t) * \varepsilon_{cha} - (\frac{E_{v2}(t)}{\varepsilon_{dis}})}{n * Q_i} \quad (3.10d)$$

In battery constraints;

Equation 3.11a represents charged energy to battery comes from solar, grid or vehicles. Equation 3.11b represents discharged energy from battery goes to grid or vehicles. Equation 3.11c represents total energy transferred to storage battery should be lower than battery capacity. Equation 3.11d represents SOC change of storage battery after every time interval. Equation 3.11e represents cost of battery depreciation. Equation 3.11f represents maintenance cost of storage battery. Maintenance cost of the battery depends totally on the amount of energy charged or discharged to the battery.

$$E_{2b}(t) = E_{s2b}(t) + E_{g2b}(t) + E_{v2b}(t) \quad (3.11a)$$

$$E_{b2}(t) = E_{b2g}(t) + E_{b2v}(t) \quad (3.11b)$$

$$\sum_{t=1}^{24} E_{2b}(t) \leq Q_{bat} \quad (3.11c)$$

$$SOC_{bat}(t+1) = SOC_{bat}(t) + \frac{\left[E_{2b}(t) * \varepsilon_{cha} - \frac{E_{b2}(t)}{\varepsilon_{dis}}\right] * (1 - k_{self})}{Q_{bat}} \quad (3.11d)$$

$$G_{dep}(t) = \frac{[1 - SOC_{bat}(t)] * k_{dep} * C_{bat}}{N} \quad (3.11e)$$

$$G_{main}(t) = \left[E_{2b}(t) * \varepsilon_{cha} + \frac{E_{b2}(t)}{\varepsilon_{dis}}\right] * C_{main}(t) \quad (3.11f)$$

In PV constraints;

Equation 3.12a represents photovoltaic power production that depends on power, incident radiation and temperature under standard test conditions. Equation 3.12b represents generated PV energy is used by either battery, vehicle and grid.

$$E_{solar}(t) \leq P_{STC} * \theta * \left[\frac{R_{PV}(t)}{R_{STC}}\right] * \left[1 + k_{temp} * (T_C(t) - T_{STC})\right] \quad (3.12a)$$

$$E_{solar}(t) = E_{s2b}(t) + E_{s2v}(t) + E_{s2g}(t) \quad (3.12b)$$

In grid constraints;

Equation 3.13a represents that purchased grid energy should be below an upper limit due to CO2 restrictions. Equation 3.13b represents that total energy transferred to the grid consists of energy from solar, battery and vehicle to grid. Equation 3.13c represents that total energy transferred from grid goes to battery and vehicle.

$$E_{g2b}(t) + E_{g2v}(t) \leq E_{upper}(t) \quad (3.13a)$$

$$E_{2g}(t) = E_{s2g}(t) + E_{v2g}(t) + E_{b2g}(t) \quad (3.13b)$$

$$E_{g2}(t) = E_{g2v}(t) + E_{g2b}(t) \quad (3.13c)$$

In economic constraints;

Equation 3.14a represents that cost of total purchasing energy is found by energy from grid to battery and vehicles. Equation 3.14b represents that revenue of total sold energy is found by total energy to grid and its price. Equation 3.14c represents that parking fee revenue depends on hourly parking fee. Equation 3.14d represents that service revenue depends on service price and energy charged to vehicles.

$$G_{buy}(t) = E_{g2}(t) * p_{buy}(t) \quad (3.14a)$$

$$G_{sell}(t) = E_{2g}(t) * p_{sell}(t) \quad (3.14b)$$

$$G_{park}(t) = N_{park}(t) * p_{park}(t) \quad (3.14c)$$

$$G_{serv}(t) = E_{2v}(t) * p_{serv}(t) \quad (3.14d)$$

Equation 3.15a represents yearly total income of station. Equation 3.15b represents yearly total expense of station. Equation 3.15c represents yearly total operation and maintenance costs of system. Equation 3.15d represents that initial investment of system consists of initial cost of storage battery, PV modules and charging station units. Equation 3.15e represents annualization of initial investment cost.

$$\mathrm{IN} = \sum_{t=1}^{8760} \left[G_{sell}(t) + G_{serv}(t) + G_{park}(t) \right] \tag{3.15a}$$

$$\mathrm{OUT} = \sum_{t=1}^{8760} \left[G_{buy}(t) + G_{dis}(t) \right] \tag{3.15b}$$

$$\mathrm{OM} = \sum_{t=1}^{8760} \left[G_{main}(t) + G_{dep}(t) \right] + G_{oper} \tag{3.15c}$$

$$C_{ini} = C_{bat} + C_{PV} + C_{sta} \tag{3.15d}$$

$$\mathrm{ANN\_INV} = \frac{C_{ini}}{\sum_{n=1}^{25} (1+d)^{-n}} \tag{3.15e}$$

Total Annualized Cost (TAC) includes annualized investment cost, income, expense and O&M costs is calculated for each year and was stated in Equation 3.16a. Income and expense are multiplied by yearly increase ratio (x_n) and O&M costs are considered constant. Then all costs of 25 years are brought to today. And it gives total value of all cash flows at time=0 which is the NPV of the system. Equation 3.16b represents Net Present Value of project.

$$\mathrm{TAC}_n = \frac{C_{ini}}{\sum_{n=1}^{25} (1+d)^{-n}} \mathrm{OUT} * (x_n) + \mathrm{OM} - \mathrm{IN} * (x_n) \tag{3.16a}$$

$$\mathrm{NPV} = \sum_{n=1}^{25} \frac{-\mathrm{TAC}_n}{(1+d)^n} \tag{3.16b}$$

4. CASE STUDY

4.1 Data

There are nearly 400 charging points in public places in Turkey. Charging sessions in these stations are not enough for generating a meaningful data set. Source of data that was used in this work is based on E-sarj Company. This company has 109 charging stations with a total capacity of 176 vehicles [35]. Company has stated that specific hourly charging information is not open to public due to privacy concerns. And it is a challenge to estimate demand of electric vehicles because of the lack of historical data. Calculating energy demand is linked uncertainties such as EV arrival times, departure times and travelled distances. Nevertheless, according to data that was provided from E-sarj Company an approximate data set on the basis of average values were formed.

This data set of charging station includes 10 vehicles. In this data set, the situation of vehicles that they are either at station or not for 24 hours were stated. Then SOC values of each vehicle for 24 hours are also listed as table. With these two tables, new two $\alpha_{i,t}$ and $\beta_{i,t}$ tables that show whether vehicles to be charged or discharged are formed. Then demand and possible EV supply are prepared according to these initial data D_t and EVS_t.

Solar radiation data used in this study are obtained NASA Surface Meteorology and Solar Energy database [36].

Temperature data which affects solar PV output in proposed region is obtained by Turkish State Meteorological Service [37].

Price of grid electricity, $p_{buy}(t)$, was taken from EPDK Tariff Table that is valid from April 1, 2018 [38].

Price of selling electricity to grid, $p_{sell}(t)$, was taken from EPDK [39] and Distribution System Monthly Usage Fee was added to base prices.

Price of parking service for vehicles, $p_{park}(t)$, was formed based on actual prices of

ISPARK which is an Istanbul Municipality company for car park service [40].

Price of charging service to vehicles, $p_{serv}(t)$, was taken form E-sarj company that supplies charging stations that allows electric vehicle charging [41]. According to Turkish regulation, per kWh electricity sale can't be made therefore companies' pricing is hourly basis. This situation is considered in this study.

Since $p_{dis}(t)$ is not currently available, a value is set according to the current market.

G_{oper} is calculated in a study 'Right Sized Parking - Parking Costs and Operating Expense Estimates' [42] by Kidder Matthews Company. In this case monthly operational cost of a parking lot is estimated in assumption section.

4.2 Assumptions

In this study, the below technical and economical values that were stated in Table 4.1 and Table 4.2 were assumed for operation of the system.

Table 4.1 : Main technical and economical parameters of case study.

Parameter	
Parking lot capacity	10 Vehicles
Installed solar capacity	5 kW
Storage battery capacity	54 kW
Charging equipment power rating	2,2 kW
a	0,05
b	0,01
$p_{sell}(t)$	0,111691285 €
$p_{park}(t)$	0,407331976 €
$p_{serv}(t)$	0,025921181 €
G_{oper}	506,7413442 €
$p_{dis}(t)$	0,090909091 €

Table 4.2 : Hourly electricity prices of Turkey.

	Hour	Price
$p_{buy}(t)$	22-06	0,043993 €
	06-17	0,071776375 €
	17-22	0,110823422 €

4.3 Scenarios

4.3.1 Scenario 1

Electric car transformation is taking place slowly in Turkey. Therefore, the number of electric vehicles in Turkey is low, and this makes realistic forecasting difficult. In this situation, two different case studies were formed in this study.

In the first case, it is predicted that the total income will increase by 10% each year. And costs will increase with same percentage and operation and maintenance costs will stay same.

In the second case, the effect of the electricity sales price to grid, the parking fee and the charging service fee on the network profit is examined. Then the first and second scenario results will be compared.

4.3.2 Scenario 2

There is an energy transformation in the world. The amount of energy generated from renewable energy sources is increasing, and environmental technologies are developing. Costs of power generation plants are falling. In addition, carbon taxes are being created through political decisions. This restricts the use of fossil-based resources and opens up space for different renewable energy technologies.

Under these circumstances, countries are making some radical decisions over the next 20 to 30 years. For example, some countries shut down nuclear reactors or stop producing gasoline vehicles.

In Turkey, such decisions have to be taken after a while. As in the case of Germany; support for renewable energy generation will be reduced by kWh per hour.

According to the results of large-scale YEKA tender held in Turkey, the state's electricity purchase price was 6.99 dolar cent per kWh [43]. In addition, in the next high-scale wind bid, a lower price has also come into play.

In Europe, wholesale electricity prices in the last five years have fallen by almost half due to excess supply. However, domestic and industrial electricity prices have not been affected by this drop. Prices continue to rise in European countries. The residential and industrial electricity prices in Turkey continues to grow. In the last 5 years, the price of the industry electricity has increased by more than 100% [44].

Under these circumstances, a situation will be set up in the second scenario according to the different prices that may occur in 2030.

For both scenarios, the net present value of the final year is derived by summing the annual present value of all cash flows, including capital investment, O & M cost, and revenue generated by the system throughout its life cycle. A project is considered financially feasible only if the resulting NPV is positive. The mathematical model used with different scenarios are operated with MATLAB.

4.4 Optimization of Annual Cost

The aim of the system is the optimization of net present value that will be incurred during the life time. Total Annualized Cost for one year is modelled depending annualization of investment cost, yearly income, expense and O&M costs. Then this value is rendered to present value with a given discount rate.

4.5 Results & Discussions

In this work, the effects of different parameters on income and expense over the total life of the system have been studied. At the same time, it was observed how NPV, an important criterion for the system, changed. Since some prices are not exactly real, they have been rounded or assumed to be real. As a result, the results in the below section have been reached.

4.5.1 Scenario 1 Results

4.5.1.1 First case results

In the first case, income is estimated to increase 10% every year. Therefore x_i variable is formed in system constraints. Then this value increases each year and enters to income and expense equation as a multiplier.

All energy transactions made in the system are specified in the table below. As can be seen, the energy purchased from the grid is more than four times the energy sold to the grid. In terms of the energy transferred to the vehicles, the amounts of energy produced from the PV panels and purchased from the grid are close to each other. This leads to a considerable decline in the amount to be paid to the grid. In addition, the energy discharged from the vehicles also ensures that the vehicles with high battery are able to direct the energy to the place where the demand is generated, so that the system can meet its own needs. All the income and expense items in the system are listed in the Table 4.3 below.

Table 4.3 : Daily energy transactions through the system.

Per day	kWh
Total energy charged to vehicles	180,4
Total energy discharged from vehicles	41,4
Total energy charged to storage battery	22
Total energy discharged from storage battery	9,01
Total energy transferred to grid	20,41
Total energy transferred from grid	88,32
Total solar power output	84,08

Income includes energy that is sold to the grid, parking fees and charging service fees. Cost includes energy cost purchased from the grid, battery depreciation and maintenance cost, operation cost of the station and initial investment.

The cost of energy purchased from the grid is three times that of the energy sold to the grid. The parking fee from vehicles is the highest amount of items in income. Battery depreciation and maintenance costs are also caused by the use of the battery as a backup storage in the system. Investment cost include storage battery, solar panels and charging stations. The system's 25-year simulation resulted in income, expense, O&M costs, and annualized investment costs are specified in the Table 4.4 below.

Table 4.4 : Yearly system incomes and expenses.

Per year	€
Energy sale to grid income	832
Charging service income	1707
Parking fee income	10556
Energy purchase cost from grid	2591
Battery depreciation cost	77
Battery maintenance cost	509
Operation cost of the station	6081
Initial investment	24790

The values are calculated as a result of a specific increase rate as previously stated. The initial investment cost was also annualized to include the account. As a result, the Net Present Value was reached and shown in Table 4.5 below.

Table 4.5 : Lifetime system incomes and expenses.

Lifetime Value	€
Income	739310,3
Expense	223851,3
O&M Cost	166674,6
Annualized Investment Cost	3606,9
Net Present Value	32625,79

4.5.1.2 Second case results

An average $p_{park}(t)$ based on the value obtained from ISPARK. This value is valid in Istanbul. According to [45] the average cost of parking in the 32 European cities is 3 euros per hour. The effect of this price change, which will be taken as the average of the European Union, on the system will be examined.

The revenue generated from the electricity sold to the grid was determined according to the renewable energy law, announced in 2011. This amount has fallen below the pre-determined average of some European countries, and in some cases the states have even initiated retrospective taxation. In addition, with the increase in renewable energy production, the price that governments are paying for selling electricity to the grid is also falling. For this reason, the situation that the electricity sale price to the grid has been lowered to below the EU average is examined.

In the first case, the cheapest tariff was selected among the hourly charging service fees determined by the E-sarj company. In Europe, according to [46] charging service fee varies across cities and countries. Accordingly, the prices have been examined and an appropriate and average price has been selected.

In below Table 4.6, the hourly parking fee for vehicles and the total annual income from this fee are stated. The third and fourth lines show the total income the system will have over the lifetime and the NPV of the system.

Table 4.6 : Effect of changing hourly parking fee.

Value	€
Hourly parking fee	3
Yearly parking fee income	77745
Lifetime Total Income	4532688,8
Net Present Value	792373,69

There is a significant increase in Net Present Value and Lifetime Total Income when the charge service fee goes higher to the current price in the EU average.

In below Table 4.7, the electricity sale price to grid and the total annual income from this sale are stated. The third and fourth lines show the total income the system will have over the lifetime and the NPV of the system.

Table 4.7 : Effect of changing electricity sale price to grid.

Value	€
Electricity sale price to grid	0,043
Yearly energy sale to grid income	320,3
Lifetime Total Income	710421,8
Net Present Value	26839,9

According to the Renewable Energy Law published in Germany in 2000, the solar energy costs were determined every year and the prices were determined again. Depending on the fall in costs, the price for electricity supplied to the grid has dropped to around 40 cents per kilowatt-hour in 2006 and around 30 cents in 2010.

When we arrive in 2018, electricity produced from solar energy can now be considered the cheapest electricity. For this year's productions, the producers gave a price of 4.3 cents / kWh for electricity from the sun [47]. This price is cheaper than electricity produced by coal producers, and even below the price given for wind energy. For this reason, this price was selected in this case.

In Table 4.8 below, the charging service fee of vehicles and the total annual income from this service are stated. The third and fourth lines show the total income the system will have over the lifetime and the NPV of the system.

Table 4.8 : Effect of changing charging service fee.

Value	€
Charging service fee	0,3
Yearly charging service income	19753,8
Lifetime Total Income	1758213,5
Net Present Value	236694,42

There are many different station operators and many different types of charging equipment in Europe. And charging service fee varies according to countries, depending on charging power rating. In this case, according to [46], the average charging price of the Dutch-based NewMotion company is chosen.

In Table 4.9 below, grid electricity price and the yearly total cost from this service are stated. The third and fourth lines show the total expense the system will have over the lifetime and the NPV of the system.

Table 4.9 : Effect of changing grid electricity price.

Value	€
Grid electricity price	0,114
Yearly energy purchase cost	3592,21
Lifetime Total Expense	280368,8
Net Present Value	22268,9

$p_{buy}(t)$, price of grid electricity, is determined by EPDK. There are three types of prices in Turkey's electricity market, which during the day, night and peak rates. In the first scenario, the average of the three types of prices was taken. However, in the second scenario, according to the Electricity Price Statistics [48], averages of the prices in 28 European countries in 2017 were taken.

4.5.1.3 Comparison of two cases

The data used in Scenario 1, Case 1, is derived from actual demand and prices. Only because the rate of electric vehicle usage is low, the annual increase in income varies according to a certain increase rate.

In the Scenario 1, Case 2, we examine the economic effects of hourly parking fee, electricity sales price, charge service fee and grid electricity price in our system.

Comparison of two cases were stated in Table 4.10 below.

Table 4.10 : Comparison of two cases.

Parameter	Case 1	Case 2	Change (%)
Hourly parking fee	0,41	3	631,7
Yearly parking fee income	10556	77745	631,7
Lifetime Total Income	739310,27	4532688,8	513,1
Net Present Value	32625,79	792373,69	2328,67
Electricity sale price to grid	0,112	0,043	-61,61
Yearly energy sale to grid income	831,98	320,3	-61,61
Lifetime Total Income	739310,27	710421,8	-3,9
Net Present Value	32625,79	26839,9	-17,73
Charging service fee	0,026	0,3	1053,84
Yearly charging service income	1706,8	19753,8	1053,84
Lifetime Total Income	739310,27	1758213,5	137,82
Net Present Value	32625,79	236694,42	625,48
Grid electricity price	0,0755	0,114	50,99
Yearly energy purchase cost	2591,17	3592,21	38,63
Lifetime Total Expense	223851,34	280368,8	25,25
Net Present Value	32625,79	22268,9	-31,74

The average hourly parking fee is determined according to ISPARK data and is accepted as 0,4073 €. The increase in this value leads to very high increase in Lifetime Total Income and Net Present Value.

Even if the sales price of electricity to the grid dropped below the half price, there was a great decrease in yearly total energy sale to grid, but there was not much decrease in Lifetime Total Income and NPV.

When the charging service fee for vehicles rises more than 10 times, the yearly charging service income is almost 20 times higher than the Scenario 1 value. This increase is also reflected in the Lifetime Total Income and NPV in the positive direction.

When the grid electricity price doubles to the average of 28 European countries, the yearly energy purchase cost increases by nearly 40%. In this case, there is a 25%

increase in lifetime total expense. As a result, Net Present Value is dropping more than 30%.

4.5.2 Scenario 2 results

In this scenario, average price of grid electricity is thought to increase by 15% per year. The electricity sale price for the grid was accepted as 6.99 dollars per kWh, as mentioned earlier. The hourly parking fee in Istanbul has transferred to 2030 in a way that matches previous increases. Also, an increase of 10% per year was done for charging service. There is no reference to the energy discharging price from the vehicles. Both the increase in electricity prices and the reduction in the price of electricity sold to the grid have kept this price constant in this scenario. Battery maintenance and depreciation costs were kept constant. The operating cost of the station has increased due to the inflation rate.

Yearly system incomes and expenses are stated in Table 4.11 below

Table 4.11: Yearly system incomes and expenses.

Per year	€
Energy sale to grid income	454
Charging service income	5357
Parking fee income	18957
Energy purchase cost from grid	13863
Battery depreciation cost	77
Battery maintenance cost	509
Operation cost of the station	19084

The basic income and cost items on the system are shown at the top. There is a decline in electricity sales to the mains according to one scenario.

In this scenario and Table 4.12 below, a negative NPV is reached with a further increase in expenditure and O & M costs, despite the increase in income over 25 years. The biggest reason for this is the high increase in the price of electricity from the grid. In this scenario, the rate of increase is assumed to be 15% per year. The variation of the NPV value with respect to this increase is examined below according to the different rates of increase.

Table 4.12: Lifetime system incomes and expenses.

Lifetime Value	€
Income	1398346
Expense	857881,5
O&M Cost	491763,9
Annualized Investment Cost	3606,9
Net Present Value	-51738,6

As it is seen in the table, the increase in NPV value is negative in the Scenario 2 with rate of 15%. According to the analysis made, if this percentage is lower, the NPV value tends to increase after a certain rate. It can be seen from the Figure 4.1 that this ratio is around 11% on average.

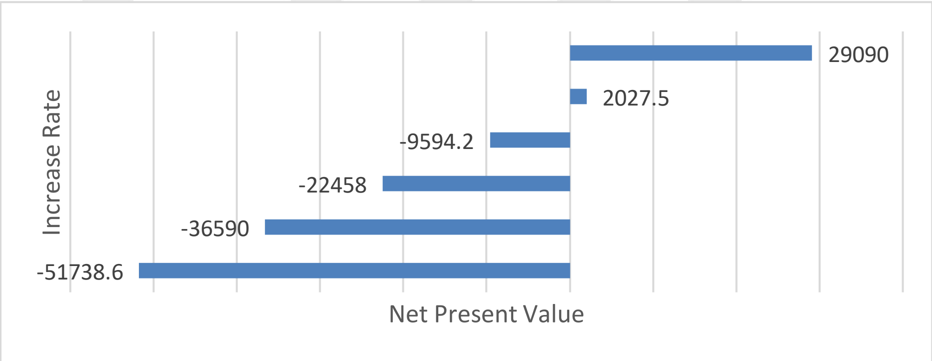

Figure 4.1 : Relation between electricity price increase and Net Present Value.

4.5.3 Comparison of two scenarios

The data used in Scenario 1, Case 1, is derived from actual demand and prices. Only because the rate of electric vehicle usage is low, the annual increase in income varies according to a certain increase rate.

In the Scenario 1, Case 2, we examine the economic effects of hourly parking fee, electricity sales price, charging service fee and grid electricity price in our system.

In Scenario 2, an estimate is made based on prices that can be fully realized in the future, taking into account past increases.

In the Table 4.13 below, the actual prices in the first scenario and the estimated prices in the second scenario are specified. Change rates are listed.

Table 4.13: Price comparison of two scenarios.

Parameter	Scenario 1 Case 1	Scenario 2	Change (%)
Hourly parking fee	0,41	0,732	78,5
Electricity sale price to grid	0,112	0,061	-45,5
Charging service fee	0,026	0,081	211,5
Grid electricity price	0,0755	0,404	435,1

*grid electricity prices of Scenario 1, Case 1 and Scenario 2 are average prices of day, night and peak values.

The effect of price changes on Scenario 1 and Scenario 2 on changes in income, expense and O & M costs over the lifetime of the system are shown in the Table 4.14 below. Higher rates of grid electricity price and charging service fees increase lifetime income by nearly 90%. However, the high increase in the electricity sales price to the network causes the total expenses to increase by almost 300%. At the same time, with the increase in O & M costs, this situation causes the NPV of the system to fall to the negative side.

Table 4.14: Effect of prices on lifetime values and Net Present Value.

Lifetime Value	Scenario 1 Case 1	Scenario 2	Change (%)
Income	739310,3	1398346	89,1
Expense	223851,3	857881,5	283,2
O&M Cost	166674,6	491763,9	195
Net Present Value	32625,79	-51738,6	-258,6

5. CONCLUSION

This thesis focuses on the effect of different economic parameters on an electric vehicle charging station. In the study, a system with 10 vehicle capacities, solar panel support and external battery was modeled.

Firstly, a data set is created for the vehicles in the station. Later, according to this set hourly electric vehicle demand and possible electric vehicle supply, and according to the solar radiation values hourly solar production is created. According to the situation of these three variables relative to each other, operational scenarios are formed. In this section, it is decided where and how much energy transfer between the components of the system will be done. The objective function and constraints of the system are also indicated in the proposed model section.

In the first scenario, simulation results are obtained with real demand, prices and also EU prices. In the second scenario, the price parameters are determined with past behavior and possible future values.

This research can be extended in several directions. Environmental factors can be included in the model and a choice of minimizing environmental damage can be made. Alternatively, different renewable energy sources can be added or removed.

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APPENDICES

APPENDIX A: MATLAB Code

```
clc;
clear;

a_i_t=xlsread('vehicledata.xlsx','B3:K26');
b_i_t=xlsread('vehicledata.xlsx','B30:K53');
SOC_i=xlsread('vehicledata.xlsx','B58:K81');


%parking lot data
V=xlsread('stationdata.xlsx','O3:O3');
I=xlsread('stationdata.xlsx','P3:P3');
eff_cha=xlsread('stationdata.xlsx','Q3:Q3');
eff_dis=xlsread('stationdata.xlsx','R3:R3');
n=10;
k_self=xlsread('stationdata.xlsx','L3:L3');
Q_bat=xlsread('stationdata.xlsx','K3:K3');
Q_i=xlsread('stationdata.xlsx','D3:D12');


%24 saatlik D_t tablosunu olusturur
D=zeros(24,10);
for t=1:24
    for i=1:10
        D(t,i)=(a_i_t(t,i)*V*I/1000);
    end
end
D_t=(sum(D')');

%24 saatlik EVS_t tablosunu olusturur
for t=1:24;
    for i=1:10
        EVS(t,i)=b_i_t(t,i).*(SOC_i(t,i)-0.8)*Q_i(i);
    end
end
EVS_t=sum(EVS')';

R_pv=xlsread('stationdata.xlsx','G3:G26');
T_c=xlsread('stationdata.xlsx','H3:H26');
P_stc=xlsread('stationdata.xlsx','I3:I3');
%24 saatlik E_solar tablosunu olusturur
E_solar=P_stc*0.77*(R_pv/1000).*(1-0.45*(T_c-25));% <= yapilacak

E_s2b=zeros(24,1);
E_v2b=zeros(24,1);
E_s2g=zeros(24,1);
E_s2v=zeros(24,1);
E_g2v=zeros(24,1);
E_b2v=zeros(24,1);
E_b2g=zeros(24,1);
E_g2b=zeros(24,1);
E_v2g=zeros(24,1);
E_v2v=zeros(24,1);
E_2v=zeros(24,1);
E_v2=zeros(24,1);
E_2b=zeros(24,1);
E_b2=zeros(24,1);
E_g2=zeros(24,1);
E_2g=zeros(24,1);

a=xlsread('pricedata','L2:L2');
b=xlsread('pricedata','M2:M2');
p_buy=xlsread('pricedata','B2:B25');
SOC_bat=xlsread('stationdata','J3:J26');
p_sell=xlsread('pricedata','C2:C25');
for k=1:24
```

Figure A.1 : MATLAB Code of station model.

```
%first case
        if E_solar(k,1)+EVS_t(k,1)<D_t(k,1);
            E_s2v(k,1)=E_solar(k,1);
            E_v2v(k,1)=EVS_t(k,1);
            if p_buy(k,1)<=a && SOC_bat(k,1)>0.2;
                E_g2v(k,1)=D_t(k,1)-E_solar(k,1)-EVS_t(k,1);
            elseif p_buy(k,1)<=a && SOC_bat(k,1)<=0.2;
                E_g2v(k,1)=D_t(k,1)-E_solar(k,1)-EVS_t(k,1);
                E_g2b(k,1)=5*V*I/1000;
            elseif p_buy(k,1)>a && SOC_bat(k,1)>0.2;
                E_b2v(k,1)=D_t(k,1)-E_solar(k,1)-EVS_t(k,1);
            elseif p_buy(k,1)>a && SOC_bat(k,1)<=0.2;
                E_g2v(k,1)=D_t(k,1)-E_solar(k,1)-EVS_t(k,1);
            end

        %second case
        elseif E_solar(k,1)+EVS_t(k,1)==D_t(k,1);
            if D_t(k,1)>EVS_t(k,1);
                E_s2v(k,1)=E_solar(k,1);
                E_v2v(k,1)=EVS_t(k,1);
            elseif D_t(k,1)==EVS_t(k,1);
                E_v2v(k,1)=EVS_t(k,1);
            end

        %third case
        elseif E_solar(k,1)+EVS_t(k,1)>D_t(k,1);
            if D_t(k,1)>EVS_t(k,1);
                E_v2v(k,1)=EVS_t(k,1);
                E_s2v(k,1)=D_t(k,1)-EVS_t(k,1);
                if p_sell(k,1)>=b && SOC_bat(k,1)<=0.8;
                    E_s2g(k,1)=E_solar(k,1)-E_s2v(k,1);
                elseif p_sell(k,1)>=b && SOC_bat(k,1)>0.8;
                    E_s2g(k,1)=E_solar(k,1)-E_s2v(k,1);
                    E_b2g(k,1)=5*V*I/1000;
                %elseif p_sell(k,1)<0.6 && SOC_bat(k,1)<=0.8;
                    %E_s2b(k,1)=E_solar(k,1)-E_s2v(k,1);
                %elseif p_sell(k,1)<0.6 && SOC_bat(k,1)>0.8;
                    %E_s2g(k,1)=E_solar(k,1)-E_s2v(k,1);
                end
            elseif D_t(k,1)==EVS_t(k,1);
                E_v2v(k,1)=EVS_t(k,1);
                if p_sell(k,1)>=b && SOC_bat(k,1)<=0.8;
                    E_s2g(k,1)=E_solar(k,1);
                elseif p_sell(k,1)>=b && SOC_bat(k,1)>0.8;
                    E_s2g(k,1)=E_solar(k,1);
                    E_b2g(k,1)=5*V*I/1000;
                %elseif p_sell(k,1)<0.2 && SOC_bat(k,1)<=0.8;
                    %E_s2b(k,1)=E_solar(k,1);
                %elseif p_sell(k,1)<0.2 && SOC_bat(k,1)>0.8;
                    %E_s2g(k,1)=E_solar(k,1);
                end
            elseif D_t(k,1)<EVS_t(k,1);
                E_v2v(k,1)=D_t(k,1);
                if p_sell(k,1)>=b && SOC_bat(k,1)<=0.8;
                    E_v2g(k,1)=EVS_t(k,1)-E_v2v(k,1);
                    E_s2g(k,1)=E_solar(k,1);
                elseif p_sell(k,1)>=b && SOC_bat(k,1)>0.8;
                    E_v2g(k,1)=EVS_t(k,1)-E_v2v(k,1);
                    E_s2g(k,1)=E_solar(k,1);
                    E_b2g(k,1)=5*V*I/1000;
                %elseif p_sell(k,1)<0.2 && SOC_bat(k,1)<=0.8;
                    %E_v2b(k,1)=EVS_t(k,1)-E_v2v(k,1);
                    %E_s2b(k,1)=E_solar(k,1);
                %elseif p_sell(k,1)<0.2 && SOC_bat(k,1)>0.8;
                    %E_v2g(k,1)=EVS_t(k,1)-E_v2v(k,1);
                    %E_s2g(k,1)=E_solar(k,1);
                end
            end
        end
        E_2v(k,1)=E_s2v(k,1)+E_v2v(k,1)+E_b2v(k,1)+E_g2v(k,1);
        E_v2(k,1)=E_v2g(k,1)+E_v2b(k,1)+E_v2v(k,1);
        E_2b(k,1)=E_s2b(k,1)+E_g2b(k,1)+E_v2b(k,1);
        E_b2(k,1)=E_b2g(k,1)+E_b2v(k,1);
        E_g2(k,1)=E_g2v(k,1)+E_g2b(k,1);
        E_2g(k,1)=E_s2g(k,1)+E_v2g(k,1)+E_b2g(k,1);
        SOC_bat(k+1)=SOC_bat(k)+[[E_2b(k)*eff_cha-E_b2(k)/eff_dis]*(1-k_self)]/Q_bat;
end
```

Figure A.1 (continues): MATLAB Code of station model.

```
C_bat=xlsread('pricedata','G2:G2');
C_pv=xlsread('pricedata','H2:H2');
C_sta=xlsread('pricedata','I2:I2');
C_ini=C_bat+C_pv+C_sta;
k_dep=xlsread('stationdata','M3:M3');
[N]=StoBatCycle(E_2b, E_b2);
N=sum(N);
%daily battery depreciation cost
for k=1:24
    G_dep(k,1)=((1-SOC_bat(k,1))*k_dep*C_bat)/N;
end

C_main=0.05;
%battery maintenance cost calculation 1
for k=1:24;
    G_main(k,1)=(E_2b(k,1)*eff_cha+E_b2(k,1)*eff_dis)*C_main;
end

%monthly operation cost is estimated 2488,1 TL
G_oper=1590.372;

%24 saatteki bataryaya giden toplam enerji Q_bat'i gecemez
% for k=1:24
%     AAA(k,1)=E_2b(k,1);
% end
% sum(AAA)<=Q_bat;

%renewable share must be bigger than 0.6
% for k=1:24
%     RS(k,1)=(E_s2v(k,1)/E_2v(k,1))>=0.6;
% end

%cost of total purchasing energy
for k=1:24
    G_buy(k,1)=E_g2(k,1)*p_buy(k,1);
end

p_dis=xlsread('pricedata','F2:F25');
%cost of discharged energy from vehicles
for k=1:24
    G_dis(k,1)=E_v2(k,1)*p_dis(k,1);
end

%revenue of total sold energy
for k=1:24
    G_sell(k,1)=E_2g(k,1)*p_sell(k,1);
end

%N_park=istasyonda mevcut park halinde arac sayisi
%yani x_i_t veya y_i_t 'nin ikisinden birinin bire esit oldugu durum
%veya n-(x_i_t=0 and y_i_t=0)
N_park=xlsread('vehicledata','O3:X26');
p_park=xlsread('pricedata','D2:D25');
%revenue of total parking fee
for k=1:24
    for l=1:10
    G_park(k,l)=N_park(k,l)*p_park(k,1);
    end
end
G_park=sum(G_park')';

p_serv=xlsread('pricedata','E2:E25');
%revenue of total transferred energy to vehicles
for k=1:24
    G_serv(k,1)=E_2v(k,1)*p_serv(k,1);
end

%yearly total income of station
IN=G_sell+G_serv+G_park;
IN=sum(IN);
IN=IN*365;

%yearly total expense of station
OUT=sum(G_buy+G_dis);
OUT=OUT*365;
```

Figure A.1 (continues): MATLAB Code of station model.

```
%yearly total operation and maintenance costs of the system
OM=sum(G_main+G_dep)*365;
OM=OM+(G_oper*12);

%annualization of initial investment cost
d=0.14;
for y=1:25
    A(y)=(1+d)^-y;
end
A=sum(A);
Ann_InvC=C_ini/A;

%net present value of project
% TAC(1)=Ann_InvC + OUT*x(1) + OM - IN*x(1);
% TAC(2)=Ann_InvC + OUT*x(2) + OM - IN*x(2);
% .
% .
% TAC(25)=AnnInvC + OUT*x(25) + OM -IN*x(25);
% TAC(y)=Ann_InvC + OUT*x(y) + OM - IN*x(y);

x=xlsread('pricedata','K2:K26');
for y=1:25
    TAC(y)=Ann_InvC + OUT*x(y) + OM - IN*x(y);
end
TAC=TAC';

% for y=1:25
%     NPV(y)=TAC(y)*(1+d)^y;
% end
% NPV=sum(NPV(y));

for y=1:25
    NPV(y,1)=[IN*x(y)-OUT*x(y)-OM]/(1+d)^y;
end
NPV=sum(NPV)-C_ini;

lifetimeIN=sum(IN*x(:));
lifetimeOUT=sum(OUT*x(:));
lifetimeOM=OM*25;
```

Figure A.1 (continues): MATLAB Code of station model.

Table A.1 : Scenario 1, Case 1 prices.

time	p_{buy} (€/kWh)	p_{sell} (€/kWh)	p_{park} (€/h)	p_{serv} (€/kWh)	p_{dis} (€/kWh)
1	0,043993	0,111691285	0,407331976	0,025921181	0,090909091
2	0,043993	0,111691285	0,407331976	0,025921181	0,090909091
3	0,043993	0,111691285	0,407331976	0,025921181	0,090909091
4	0,043993	0,111691285	0,407331976	0,025921181	0,090909091
5	0,043993	0,111691285	0,407331976	0,025921181	0,090909091
6	0,071776375	0,111691285	0,407331976	0,025921181	0,090909091
7	0,071776375	0,111691285	0,407331976	0,025921181	0,090909091
8	0,071776375	0,111691285	0,407331976	0,025921181	0,090909091
9	0,071776375	0,111691285	0,407331976	0,025921181	0,090909091
10	0,071776375	0,111691285	0,407331976	0,025921181	0,090909091
11	0,071776375	0,111691285	0,407331976	0,025921181	0,090909091
12	0,071776375	0,111691285	0,407331976	0,025921181	0,090909091
13	0,071776375	0,111691285	0,407331976	0,025921181	0,090909091
14	0,071776375	0,111691285	0,407331976	0,025921181	0,090909091
15	0,071776375	0,111691285	0,407331976	0,025921181	0,090909091
16	0,071776375	0,111691285	0,407331976	0,025921181	0,090909091
17	0,110823422	0,111691285	0,407331976	0,025921181	0,090909091
18	0,110823422	0,111691285	0,407331976	0,025921181	0,090909091
19	0,110823422	0,111691285	0,407331976	0,025921181	0,090909091
20	0,110823422	0,111691285	0,407331976	0,025921181	0,090909091
21	0,110823422	0,111691285	0,407331976	0,025921181	0,090909091
22	0,043993	0,111691285	0,407331976	0,025921181	0,090909091
23	0,043993	0,111691285	0,407331976	0,025921181	0,090909091
24	0,043993	0,111691285	0,407331976	0,025921181	0,090909091

Table A.2 : Scenario 1, Case 2 prices.

time	p_{buy} (€/kWh)	p_{sell} (€/kWh)	p_{park} (€/h)	p_{serv} (€/kWh)	p_{dis} (€/kWh)
1	0,114000	0,043	3	0,3	0,090909091
2	0,114000	0,043	3	0,3	0,090909091
3	0,114000	0,043	3	0,3	0,090909091
4	0,114000	0,043	3	0,3	0,090909091
5	0,114000	0,043	3	0,3	0,090909091
6	0,114000	0,043	3	0,3	0,090909091
7	0,114000	0,043	3	0,3	0,090909091
8	0,114000	0,043	3	0,3	0,090909091
9	0,114000	0,043	3	0,3	0,090909091
10	0,114000	0,043	3	0,3	0,090909091
11	0,114000	0,043	3	0,3	0,090909091
12	0,114000	0,043	3	0,3	0,090909091
13	0,114000	0,043	3	0,3	0,090909091
14	0,114000	0,043	3	0,3	0,090909091
15	0,114000	0,043	3	0,3	0,090909091
16	0,114000	0,043	3	0,3	0,090909091
17	0,114000	0,043	3	0,3	0,090909091
18	0,114000	0,043	3	0,3	0,090909091
19	0,114000	0,043	3	0,3	0,090909091
20	0,114000	0,043	3	0,3	0,090909091
21	0,114000	0,043	3	0,3	0,090909091
22	0,114000	0,043	3	0,3	0,090909091
23	0,114000	0,043	3	0,3	0,090909091
24	0,114000	0,043	3	0,3	0,090909091

Table A.3 : Scenario 2 prices.

time	p_{buy} (€/kWh)	p_{sell} (€/kWh)	p_{park} (€/h)	p_{serv} (€/kWh)	p_{dis} (€/kWh)
1	0,235374	0,06094307	0,731511	0,0813517	0,090909091
2	0,235374	0,06094307	0,731511	0,0813517	0,090909091
3	0,235374	0,06094307	0,731511	0,0813517	0,090909091
4	0,235374	0,06094307	0,731511	0,0813517	0,090909091
5	0,235374	0,06094307	0,731511	0,0813517	0,090909091
6	0,384021	0,06094307	0,731511	0,0813517	0,090909091
7	0,384021	0,06094307	0,731511	0,0813517	0,090909091
8	0,384021	0,06094307	0,731511	0,0813517	0,090909091
9	0,384021	0,06094307	0,731511	0,0813517	0,090909091
10	0,384021	0,06094307	0,731511	0,0813517	0,090909091
11	0,384021	0,06094307	0,731511	0,0813517	0,090909091
12	0,384021	0,06094307	0,731511	0,0813517	0,090909091
13	0,384021	0,06094307	0,731511	0,0813517	0,090909091
14	0,384021	0,06094307	0,731511	0,0813517	0,090909091
15	0,384021	0,06094307	0,731511	0,0813517	0,090909091
16	0,384021	0,06094307	0,731511	0,0813517	0,090909091
17	0,592935	0,06094307	0,731511	0,0813517	0,090909091
18	0,592935	0,06094307	0,731511	0,0813517	0,090909091
19	0,592935	0,06094307	0,731511	0,0813517	0,090909091
20	0,592935	0,06094307	0,731511	0,0813517	0,090909091
21	0,592935	0,06094307	0,731511	0,0813517	0,090909091
22	0,235374	0,06094307	0,731511	0,0813517	0,090909091
23	0,235374	0,06094307	0,731511	0,0813517	0,090909091
24	0,235374	0,06094307	0,731511	0,0813517	0,090909091

Table A.4 : Initial Investment Cost.

Equipment	€
Storage Battery	4582,5
Solar Equipment	2583,9
Charging Equipment	17623,5
Total	24789,9

Table A.5 : Average hourly radiation and temperature.

time	Solar Radiation (W/m2)	Temperature
1	0	12,83947477
2	0	12,75976823
3	0	13,07833935
4	0	15,22056142
5	4,4	12,92790624
6	44,9	16,20081717
7	137,6	14,06464616
8	247,9	14,69589802
9	362	17,00587494
10	448,2	14,2087519
11	503	17,04014464
12	515,7	11,89736161
13	477,6	12,23903537
14	402,7	16,55491371
15	308,9	15,64315922
16	203,3	11,05960253
17	112,4	13,1151834
18	41,5	14,54721788
19	5,1	12,61383624
20	0	15,82252953
21	0	11,63606281
22	0	11,03881619
23	0	12,99087819
24	0	15,1019302

Table A.6 : Park availability table.

time	i=1	i=2	i=3	i=4	i=5	i=6	i=7	i=8	i=9	i=10
1	0	0	0	0	1	0	0	0	0	0
2	0	0	0	0	1	0	0	0	0	0
3	0	0	0	0	1	0	0	0	0	0
4	0	0	0	0	1	0	0	0	0	0
5	0	0	0	0	1	0	0	0	0	0
6	0	0	0	0	1	0	0	1	0	0
7	0	1	0	0	1	0	0	1	0	0
8	1	1	1	0	1	0	1	1	0	0
9	1	1	1	0	1	0	1	1	0	0
10	1	1	1	0	0	0	1	1	0	0
11	1	1	1	1	0	0	1	1	0	0
12	1	1	1	1	0	1	1	1	1	0
13	1	1	1	1	0	1	0	0	1	0
14	1	0	1	1	0	1	0	0	1	0
15	1	0	1	1	0	1	0	0	1	0
16	1	0	1	0	0	1	0	0	1	1
17	0	0	1	0	0	0	0	0	0	1
18	0	0	1	0	0	0	0	0	0	1
19	0	0	1	0	0	0	0	0	0	1
20	0	0	1	0	0	0	0	0	0	1
21	0	0	0	0	0	0	0	0	0	1
22	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0

Table A.7 : $\alpha_{i,t}$ table.

time	i=1	i=2	i=3	i=4	i=5	i=6	i=7	i=8	i=9	i=10
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	1	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	1	0	0	1	0	0
7	0	1	0	0	0	0	0	1	0	0
8	1	1	1	0	1	0	1	1	0	0
9	1	1	1	0	0	0	1	1	0	0
10	1	1	1	0	0	0	1	1	0	0
11	1	1	1	1	0	0	1	1	0	0
12	1	1	1	1	0	1	1	1	1	0
13	1	1	1	1	0	1	1	1	1	0
14	1	0	1	1	0	1	0	1	1	0
15	1	0	1	1	0	1	0	0	1	0
16	1	0	1	1	0	1	0	0	1	1
17	0	0	1	1	0	1	0	0	1	1
18	0	0	1	1	0	1	0	0	1	1
19	0	0	1	0	0	1	0	0	1	1
20	0	0	1	0	0	1	0	0	1	1
21	0	0	0	0	0	0	0	0	1	1
22	0	0	0	0	0	0	0	0	1	1
23	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0

Table A.8 : $\beta_{i,t}$ table.

time	i=1	i=2	i=3	i=4	i=5	i=6	i=7	i=8	i=9	i=10
1	0	0	0	0	1	0	0	0	0	0
2	0	0	0	0	1	0	0	0	0	0
3	0	0	0	0	1	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	1	0	0	0	0	0
6	0	0	0	0	0	0	0	1	0	0
7	0	0	0	0	1	0	0	1	0	0
8	0	0	0	0	0	0	0	1	0	0
9	0	0	1	0	1	0	0	0	0	0
10	0	0	0	0	0	0	0	1	0	0
11	0	0	1	1	0	0	0	0	0	0
12	0	0	0	0	0	0	0	1	0	0
13	0	0	1	0	0	0	0	0	0	0
14	1	0	0	0	0	0	0	0	1	0
15	0	0	1	0	0	0	0	0	0	0
16	1	0	0	0	0	0	0	0	1	0
17	0	0	1	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0
19	0	0	1	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0

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- Mercan M. C., Kayalica Ö., Kayakutlu G., 2018: Economic Evaluation of PV-Assisted Charging Stations. *International Congress – REMOO Energy*, May 29-31, 2018 Venice, Italy.