SITE SELECTION AND INVESTMENT ANALYSIS OF SOLAR POWERED ELECTRIC VEHICLE CHARGING STATION IN THE CITY OF ISTANBUL

(İSTANBUL'DA GÜNEŞ ENERJİLİ ELEKTRİKLİ ARAÇ ŞARJ İSTASYONU YER SEÇİMİ VE YATIRIM ANALİZİ)

by

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Thesis

Submitted in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

in

INDUSTRIAL ENGINEERING

in the

GRADUATE SCHOOL OF SCIENCE AND ENGINEERING

of

GALATASARAY UNIVERSITY

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July 2023

This is to certify that the thesis entitled

SITE SELECTION AND INVESTMENT ANALYSIS OF SOLAR POWERED ELECTRIC VEHICLE CHARGING STATION IN THE CITY OF ISTANBUL

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ACKNOWLEDGEMENTS

I hope the methods and models included in this study will be useful to the literature and everyone working in this field, and I will contribute to yielding a sustainable and greener future for all.

I would like to express my sincere thanks to my esteemed teacher Prof. A. Çağrı TOLGA who guided me with his knowledge and experience, patiently answering all my questions at every stage of this study.

And my dear husband, A. Cüneyt, thank you for supporting me every second of every moment for achieving my goals.

July 2023
Serra MANDACI

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LIST OF SYMBOLS

EV	: Electric Vehicle
EVCS	: Electric Vehicle Charging Station
IICEC	: Istanbul International Center for Energy and Climate (Sabanci University)
ISPARK	: İSPARK İstanbul Otopark İşletmeleri Ticaret Anonim Şirketi (ISPARK Istanbul Parking Lot Management Trade Joint Stock Company)
MCDM	: Multicriteria Decision Making
PVCS	: Photo-Voltaic Charging Station
WEDBA	: Weighted Euclidean Distance Based Approach
IRR	: Internal Rate of Return
NPV	: Net Present Value
DPP	: Discounted Payback Period

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ABSTRACT

In parallel with the goal of reducing the use of fossil fuels, adopted by many authorities on a global scale within the scope of creating a sustainable future, the use of electric vehicles has started to increase, and it is expected to become more widespread in Türkiye in the upcoming years. However, the prevalence of electric vehicle charging stations (EVCSs) is a factor that directly affects consumer appetite. From this perspective, to make the transition to electrification in transportation in the smoothest way, the city of Istanbul, which is the most populous city of Türkiye, should be prepared in terms of infrastructure. In this study, when available opportunities are evaluated, ISPARK, the subsidiary of Istanbul Metropolitan Municipality that provides parking services, is seen as a great opportunity for this transition. As a result of the evaluation made between the parking lots, site selection suggestions were made for the installation of 3 different power charging stations, which are powered by renewable energy sources, in order to provide a sustainable solution. Among the existing parking lots as of the end of 2022 in Istanbul, site selection and ranking are made with weighted Euclidean distance-based approach (WEDBA) to install EVCSs. Due to the working principle of solar panels, only open car parks of ISPARK were used in this study. The feasibility of installing an EVCS that generates electricity from solar energy, i.e., photovoltaic charging station (PVCS), with micro wind turbines as an intelligent backup system, is examined among 150 parking lots. Considering the potential solar energy productivity and the mean density of the wind, 8 criteria were determined for the problem, parking lots are ranked for each of the 120, 180 and 360 kW DC charging station power scenarios and the first 5 parking lots for each scenario are presented in a table. As a result of the market research, the approximate cost of electric vehicle charging stations are determined. In line with the low, medium and high scenario electric vehicle stock market predictions of the Ministry of Industry and Technology, cash flow calculations are made in US Dollars. According to the results of the WEDBA application, potential costs and returns between 2023 and 2030 of the PVCS

investment are examined in 3 different scenario and net present value, internal rate of return and discounted payback period are calculated for guiding the power selection of the charging station. The result of the investment analysis differs according to the economic return that the investor expects and the liquidity risk s/he would like to take.

ÖZET

Sürdürülebilir bir gelecek yaratma amacı kapsamında küresel ölçekte birçok otorite tarafından benimsenen fosil yakıt kullanımının azaltılması hedefine paralel olarak elektrikli araç kullanımı artmaya başlamış ve önümüzdeki yıllarda Türkiye'de daha da yaygınlaşması beklenmektedir. Ancak elektrikli araç şarj istasyonlarının yaygınlığı elektrikli araç alımında tüketici iştahını doğrudan etkileyen bir faktördür. Bu açıdan bakıldığında ulaşımda elektrifikasyona geçişin en sorunsuz şekilde yapılabilmesi adına Türkiye'nin en kalabalık ili olan İstanbul'un alt yapı olarak hazırlanması gerekmektedir. Bu çalışmada, mevcut imkanlar değerlendirildiğinde, İstanbul Büyükşehir Belediyesi'nin otopark hizmeti veren iştiraki olan İSPARK A.Ş.'nin bu geçiş için büyük bir fırsat olduğu görülmektedir. Otoparklar arasında yapılan değerlendirme sonucunda, sürdürülebilir bir çözüm sağlayabilmek adına, gücünü yenilenebilir enerji kaynaklarından alan 3 farklı güçte şarj istasyonu kurulumu için yer seçim önerilerinde bulunulmuştur. İstanbul'da 2022 yıl sonu itibariyle mevcut otoparklar arasında, elektrikli araç şarj istasyonlarının kurulumu için ağırlıklı Öklid mesafesine dayalı yaklaşım (WEDBA) ile yer seçimi ve sıralama yapılmıştır. Güneş panellerinin çalışma prensibi gereği, İSPARK'ın yalnızca açık otoparkları bu çalışmada kullanılmıştır. Güneş enerjisinden elektrik üreten bir elektrikli araç şarj istasyonunun, yani fotovoltaik şarj istasyonunun, akıllı yedek sistem olarak mikro rüzgar türbinleriyle kurulmasının fizibilitesi, 150 otopark arasında incelenmiştir. Potansiyel güneş enerjisi verimliliği ve rüzgarın ortalama yoğunluğu dikkate alınarak, problem özelinde 8 kriter belirlenmiş, 120, 180 ve 360 kW DC şarj istasyonu güç senaryosunun her biri için otoparklar sıralanmıştır ve her senaryo için ilk 5 otopark tablo halinde sunulmuştur. Yapılan piyasa araştırması sonucu elektrikli araç şarj istasyonlarının yaklaşık maliyeti belirlenerek T.C. Sanayi ve Teknoloji Bakanlığı'nın düşük, orta ve yüksek senaryolu elektrikli araç stok piyasası öngörüleriyle uyumlu bir şekilde Amerikan Doları cinsinden nakit akış hesaplaması yapılmıştır. WEDBA uygulamasının sonuçlarına göre güneş enerjili elektrikli şarj istasyonu yatırımının 2023-

2030 yılları arasındaki potansiyel maliyetleri ve getirileri 3 farklı senaryoda incelenmiş ve şarj istasyonunun güç seçimine destek olabilecek net bugünkü değer, iç verim oranı ve indirgenmiş geri ödeme süresi hesaplanmıştır. Yatırımcının beklediği ekonomik geri dönüş ve almak istediği likidite riskine göre yatırım analizinin sonucu farklılık göstermektedir.

1. INTRODUCTION

Reducing fossil fuel dependence is recognized as one of the major concerns in the world today for creating a sustainable future and therefore dissemination of electric vehicles is supported by different authorities around the world. At earlier times, electric vehicles were not developed enough to be competitive compared to the gas-fueled cars. But in today's world, most of the well-known automobile brands have developed electric and/or hybrid models with intelligent systems to offer environment-friendly products worldwide. With the positive developments in the battery technologies, production of electric vehicles has been greatly affected. But lack of availability of recharging infrastructure influences the customer appetite in electric vehicle market and this situation is mostly observed in the developing countries such as Türkiye. According to the Sabanci University - Istanbul International Center for Energy and Climate 's (IICEC) report on Türkiye Electric Vehicle Outlook (2021)[1], even if the electric vehicle sales increased in 2021, the market share is still below 1% in Türkiye. It is aimed to achieve a more rapid increase in the market share with the expected significant impact of the introduction of TOGG (Türkiye's Automobile Enterprise Group, introduced from the beginning as an electric vehicle producer). Also, other brands have projects to offer more electric vehicle models to the Turkish market. However, although there are some private companies established to install electric vehicle charging stations, there is still a significant gap in this sector. As stated in IICEC's report, total number of charging stations in Türkiye was above 3,000 due to the private sector investments. It is also very important to improve the accessibility of the electric vehicle charging stations in cooperation with a local government.

On city basis, it can be stated that densely populated cities require more investments than others. Istanbul is a mega city in Türkiye with almost 16 million inhabitants and Istanbul

[1]Source: https://iicec.sabanciuniv.edu/tevo

Metropolitan Municipality offers local services to all residents of Istanbul in conformity with the local governance standards of the 21st century with various projects including superstructural and infrastructural projects. When transition to electrification of transportation sector accelerates, Istanbul's infrastructure should be ready for a smooth transition to respond to needs of the residents. With this objective in mind, ISPARK which is one of the subsidiaries of Istanbul Metropolitan Municipality and that provides parking lot service in many spots of the city, could be supportive for expanding the electric vehicle charging stations infrastructure. ISPARK operates in 37 districts out of 39 districts in Istanbul and has 745 parking lots with different size and capacity. 212 of the parking lots are in the Asian side and 533 are in the European side.

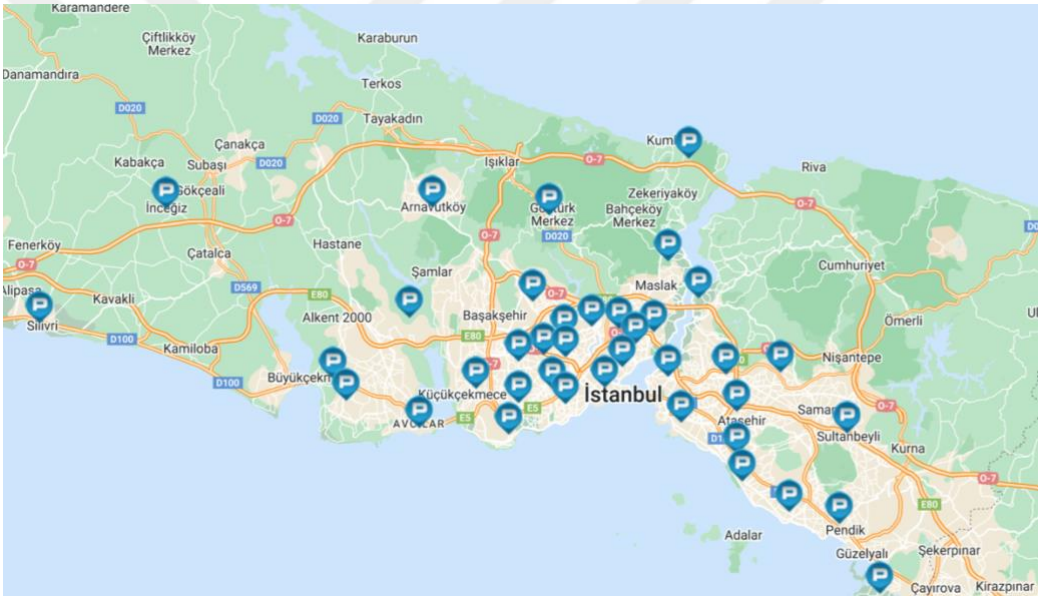

Figure 1.1**:** Districts of Istanbul where ISPARK has parking lots.[2]

With this information in hand, ISPARK's parking lots can be considered as an opportunity to provide electric vehicle charging stations. This study makes a scientific site selection with multi-criteria decision-making among ISPARK parking lots and assign rankings in terms of their efficiency to install an EVCS, that generates electricity from solar energy for contributing to yield a sustainable future. Also, micro wind turbines are added to the power generation system as a backup. PVCS installations with 120 kW, 180 kW and 360 kW power are examined from investment perspective and suggestions are

[2] Source: https://ispark.istanbul/otoparklarimiz/

made about which power station should be selected. In the upcoming sections, some of the findings from literature review are presented, materials and methods included in this study are defined, WEDBA application is presented with minimum required slot calculation and appropriate multi-criteria that are introduced for selection among parking lots. Then, installing PVCSs with micro wind turbines are financially analyzed in low, medium, and high scenario with associated approximate costs and benefits. Net present value, internal rate of return, and discounted payback periods are calculated. Results are presented in the empirical study section and suggestions for further analysis are given in conclusion.

2. LITERATURE REVIEW

Over the past years, since the electric vehicles have become a hot topic, various methods have been applied by scholars to help decision makers effectively determine the location and/or size of the proposed electric vehicle charging stations (EVCSs). A great portion of these studies include multi criteria decision making.

Guo & Zhao (2015) studied optimal site selection problem of electric vehicle charging station with fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS); Feng et. al. (2021) developed an integrated multi-criteria decision-making (MCDM) method through the linguistic entropy weight method and fuzzy axiomatic design for selecting a suitable site for EVCS; Erbaş et. al. (2018) applied a geographic information system (GIS)-based multi criteria decision analysis (MCDA) approach to address the EVCS site selection in Istanbul. Then, this study used fuzzy analytical hierarchy process (AHP) and TOPSIS methods for choosing the optimal EVCS sites. Liu et. al. (2019) introduced multiple interrelated criteria for EVCS site selection problems and proposed an integrated MCDM approach by a grey decision-making trial and evaluation laboratory (DEMATEL) with uncertain linguistic multi-objective optimization by ratio analysis and full multiplicative form (UL-MULTIMOORA) for determining the most suitable EVCS site.

There are also some studies where EVCSs are powered by solar energy, i.e., photovoltaic charging station (PVCS), but they are not very common compared to the others. Khan et. al. (2018) conducted a comprehensive review on solar powered EVCS, and their study includes various technical details on solar powered EVCS that may guide everyone working on this subject. Ji et. al. (2020) studied optimizing the locations and sizes of solar assisted electric vehicle charging stations in an urban area. Chen et. al. (2014) investigated the interdependent interrelationship and influential weights among criteria for solar farms

site selection and utilized a hybrid MCDM model including DEMATEL and DEMATEL-based analytic network process (DANP) based on GIS. Dang et. al. (2021) considered the charging demand of electric ships and studied PVCS location selection for islands with VIKOR and AHP, Zhou et. al. (2020) proposed a practical model with GIS and TODIM (an acronym in Portuguese of interactive MCDM, *Tomada de Decisao Interativa Multicriterio*) for location decision of PVCS and conducted an empirical study for the city of Beijing. These studies are helpful for building a background for this paper, since solar power is included to the proposed model in this study.

There are two more EVCS location selection research in the current literature to the best of author's knowledge, that include analysis on Istanbul. Kaya et. al. (2020) identified the most suitable charging location alternatives based on GIS and they evaluated the current and proposed EVCS location alternatives with multi-criteria decision approach. Kaya et. al (2021) focused on the exact locations of charging stations for five large EVCS companies in Istanbul and developed a three-step methodology for analyzing those locations.

Overall, there are many studies carried out on optimal EVCS site selection and ranking with different methods, but a few studies exist on PVCS site selection. It is obvious that MCDM methods are widely found useful in selection problems since they help combining qualitative and quantitative characteristics.

Scholars have proposed different indicators, metrics, and methods for investment decision making. Hazen & Magni (2021) proposed to break down a risky net present value (NPV) into a risk sensitive extended average internal rate of return (AIRR); Percoco & Borgonovo (2012) highlighted the use of sensitivity analysis for both internal rate of return (IRR) and NPV and extended the Differential Importance Measure accordingly; Juhász (2011) stated that NPV and IRR together guarantee the making of investment-profitability decisions, NPV as measuring the asset growth and IRR as reflecting the profitibality on capital. Bhandari (2009) stated that some methods in the literatüre do not ensure profitability and liquidity together, but discounted payback period emphasizes both. San Ong & Thum (2013) used NPV and payback period for assessing capital costs of a PV Project in Malaysia; Lin et. al. (2015) used payback period to assess economic

viability of residential solar water heaters in Taiwan. Kessler (2017) compared energy payback and simple payback period for solar PV systems.

Although debates on the use of various methods for investment decision-making keep going on with various arguments, NPV, IRR and payback period are commonly used to assess different financial aspects of investments.

3. MATERIALS AND METHODS

As mentioned earlier, ISPARK has 745 parking lots with different sizes and capacity. Among these parking lots, 469 of them are available for public use while others are only open for subscriber use or are completely rented by rent-a-car companies or different firms. There are basically three types of parking lots: open, multistorey, and on-street parking lots. Open parking lots are subject to this study due to the photovoltaic nature of planned charging stations; therefore 469 parking lots are narrowed down to 152. Also, when dropping the parking data with incomplete information, 150 parking lots are left in the main data. A location-allocation problem model is built based on the criteria that is specific to the MCDM problem. A ranking is assigned to the parking lots based on their suitability for installing a photovoltaic charging station with micro wind turbines and the application is evaluated. To assess the economic viability, net present value, internal rate of return, and payback periods of installing 120 kW, 180 kW, and 360 kW powered PVCSs are calculated. Materials and methods that are used in this study can be found in this section in detail. Next section (Empirical Study) consists of the customized decision steps specialized for the Istanbul case.

3.1. WEDBA

As Rao & Singh (2011) defined, The Weighted Euclidean Distance Based Approach calculates weighted distances of alternatives from the most and least desired situations. The most desired situation is defined as the ideal point, or optimum point, and the least desired situation is defined as the non-ideal point, or non-optimum point.

In the range of values for each attribute, such points are also defined as the best and the worst values. Therefore, the alternative that has the best value for each attribute is the optimum point and the alternative that has the worst value for each attribute is the non-optimum point. In some real cases, a certain alternative may have all the best or the worst values for all attributes. Then, the optimum or non-optimum point can be marked as a reference when comparing other alternatives quantitatively and it can be considered as a feasible solution. This comparison then leads to a numerical difference that measures the efficiency of alternatives (i.e., the index score of alternatives). The higher the index score, the further the alternative is to the optimal state, and vice versa. The aim is to find a feasible solution which, as far as possible, would achieve the ideal outcome. Three types of attribute weights are taken into consideration in this method: objective weight, subjective weight and integrated weight.

Step 1: Construct the decision matrix.

The decision matrix includes the values of attributes for each alternative. Usually, the i^{th} alternative with n attributes is denoted as $Y_i = (y_{i1}, \dots, y_{ij}, \dots, y_{in})$ where y_{ij} is the performance value of attribute j for alternative i. ($for\ i = 1, \dots, m; j = 1, \dots, n$)

$$D = \begin{bmatrix} y_{11} & \cdots & y_{1j} & \cdots & y_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ y_{i1} & \cdots & y_{ij} & \cdots & y_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ y_{m1} & \cdots & y_{mj} & \cdots & y_{mn} \end{bmatrix} \quad (1)$$

Step 2: Standardize the decision matrix.

Standardized values of attribute data are often referred to as standard scores. A significant characteristic of standard scores is that they have a mean of 0 and a variance of 1 (that is, their standard deviation equals 1).

$$D' = \begin{bmatrix} Z_{11} & \cdots & Z_{1j} & \cdots & Z_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ Z_{i1} & \cdots & Z_{ij} & \cdots & Z_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ Z_{m1} & \cdots & Z_{mj} & \cdots & Z_{mn} \end{bmatrix} \quad (2)$$

where,

$$Z_{ij} = \frac{x_{ij} - \mu_j}{\sigma_j} \quad (3)$$

$x_{ij} = \frac{y_{ij}}{max_j(y_{ij})}$; if j[th] attribute is considered beneficial (4)

$x_{ij} = \frac{min_j(y_{ij})}{y_{ij}}$; if j[th] attribute is considered non-beneficial (5)

$$\mu_j = \frac{1}{m}\sum_{i=1}^{m} x_{ij} \quad (6)$$

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^{m}(x_{ij} - \mu_j)^2}{m}} \quad (7)$$

Step 3: Define the ideal and non-ideal points.

The ideal points which are denoted by "a*" and anti-ideal points which are denoted by "b*" are obtained from standardized decision matrix.

$$a^* = \{a_j^*\} \text{ and } b^* = \{b_j^*\} \text{ where } j = 1, \dots, n \quad (8)$$

Step 4: Decide the weights of attributes.

The weights can be decided by the decision maker either based on the data given in the decision matrix as objective weights or based on the decision maker's subjective preferences or by integrating both objective weights and subjective preferences.

i. Objective weights

To calculate importance of the attributes, Rao (2007) suggested the entropy method for objective weights of. Entropy is using probability theory to calculate the uncertainty in

the information. If an attribute has very similar values amongst all the alternatives, it is considered less important than other attributes, therefore a small weight is assigned to that attribute since it does not help to differentiate alternatives. The entropy value E_j can be measured with the amount of information in the decision that is included in the decision matrix and linked to each attribute as in the following equation:

$$E_j = \frac{-(\sum_{i=1}^{m} p_{ij} \ln p_{ij})}{\ln m} \text{ ; j=(1, …, n)} \tag{9}$$

where performance rating p_{ij} is,

$$p_{ij} = \frac{y_{ij}}{\sum_{k=1}^{m} y_{kj}} \tag{10}$$

For each alternative *i*, the value of attribute *j* is y_{ij}, and *m* is the total number of alternatives. For the average intrinsic information contained by each attribute, the degree of difference (d_j) is calculated as follows:

$$d_j = 1 - E_j \text{ ; } (1 \leq j \leq n) \tag{11}$$

For each attribute *j*, the objective weight w_j is calculated as:

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{12}$$

ii. Subjective weights

The decision maker can assign weights to each attribute based on his/her preferences among the attributes for the considered problem. The weights may be assigned on the basis of an arbitrary or systematic method of determining relative importance.

iii. Integrated weights

Those characteristics can be integrated as follows, where the decision maker wants to use both objective and subjective weights of an attribute:

$$w_j^I = \frac{w_j^O \times w_j^S}{\sum_{k=1}^{n} w_k^O \times w_k^S} \tag{13}$$

Where w_j^O and w_j^S are the objective and subjective weights and w_j^I is the integrated weight of the j^{th} attribute, respectively.

Step 5: Calculate weighted Euclidean distance, index score, and ranking.

As defined earlier, the best possible alternative is considered as the ideal solution where the worst possible alternative is called the non-ideal solution. The concept of WEDBA basically requires that the chosen alternative should have the shortest distance to the ideal solution whereas it should have the farthest distance to the non-ideal solution. The distance is calculated in the Euclidean form that measures the distance between two points. For each alternative, the overall performance index score can be determined by its Euclidean distance to ideal and non-ideal solutions. The alternatives are not directly compared among themselves but with the ideal and non-ideal solutions, therefore the distance is interrelated with weights of the attributes and should be included in the distance measurement. For this reason, weighted Euclidean distances are incorporated in WEDBA.

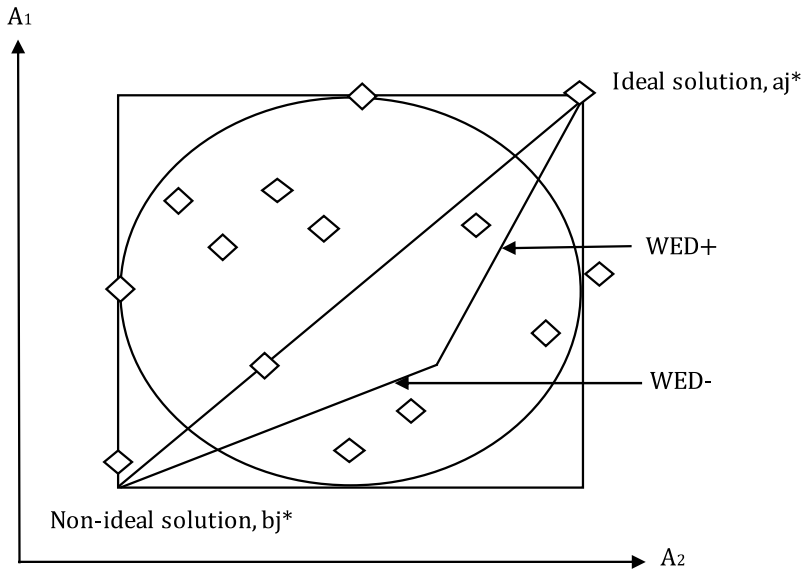

Figure 3.1**:** In case of two attributes, Euclidean distance of an alternative to ideal and non-ideal solutions.

The Euclidean distance of an alternative to ideal and non-ideal solutions, aj* and bj*, where the real domain is in the rectangular box, is shown in the figure. As known in the mathematics literature, the Euclidean distance between two points, say *P* and *Q*, in *n* dimensional space is basically the length of the line segment, *PQ*. If points are to be represented in a Cartesian coordinate in Euclidean n-space, say $P = (p_1, \dots, p_n)$ and $Q = (q_1, \dots, q_n)$, the distance is calculated by $d(PQ) = \sqrt{\sum_{i=1}^{n}(p_i - q_i)^2}$.

WED_i^+ stands for the weighted Euclidean distance between an alternative *i* and ideal point *a** and WED_i^- for the distance between an alternative *i* and non-ideal point *b**.

$$WED_i^+ = \sqrt{\sum_{j=1}^{n}\left\{w_j \,.\, (Z_{ij} - a_j^*)\right\}^2} \; ; i = (1, \dots, m) \tag{14}$$

$$WED_i^- = \sqrt{\sum_{j=1}^{n}\left\{w_j \,.\, (Z_{ij} - b_j^*)\right\}^2} \; ; i = (1, \dots, m) \tag{15}$$

Therefore, the index score of an alternative i is,

$$Index\ Score_i = \frac{WED_i^-}{WED_i^+ + WED_i^-} \tag{16}$$

If the index values are higher, as they represent a relative closeness of alternative solutions to an ideal solution, it will make alternatives more desirable. The alternatives are ranked according to their index scores. Practical considerations should be made by the decision maker before giving any final decision.

3.2. Investment Analysis

Persons and organizations that plan to direct their resources to new investments should evaluate investment alternatives carefully and make preferences by considering their

resource limits. In most cases, cost is the main resource limit. As a result, there are many methods in the literature to help investors analyze projects financially. Although each method has different weaknesses and there are some discussions on the use of various methods in terms of their accuracy, net present value, internal rate of return and payback method are some of the commonly used methods to assess economic return.

3.2.1. Net Present Value

The NPV approach involves discounting all future cash flows to the present, arguing that calculating the net present economic value of the project is more meaningful for an investor than its future uncertain values. It's basically defined as the following (Khan, 1999, as cited in Žižlavský, 2014):

$$NPV = \sum_{t=0}^{n} \frac{NCF_t}{(1+i)^t} \tag{17}$$

Where NPV is the net present value, NCF_t is the net cash flow of the project in year t and i is the discount rate.

Future and present worth of a cashflow can also be calculated to be included in NPV calculation as in Equation 18 if the discount rate is not constant for the cashflow.

$$FV = PV(1+i)^t \tag{18}$$

3.2.2. Internal Rate of Return

The internal rate of return of an investment is simply the interest rate that equates the present value of net cash flows to zero.

$$PV\ (i^*) = \sum_{t=0}^{n} NCF_t(1+i^*)^{-t} \equiv 0 \tag{19}$$

Where i^* is the internal rate of return. The investor's minimum attractive rate of return (MARR) should be less than the internal rate of return for a pure investment type project.

3.2.3. Payback Period

Payback method measures the liquidity risk and therefore it is treated as a supplementary method. Payback is the smallest number of periods that is required for cumulative net cash flows to equal the initial investment cost. The conventional method ignores the time value of the money, which is the undiscounted payback:

$$C_0 = \sum_{t=1}^{N^*} NCF_t \tag{20}$$

Where C_0 is the initial investment cost and N^* is the payback period.

To include time value of the money to the problem, the method can be modified as discounted payback period (DPP) by discounting all cashflows. If all cash flows are discounted at i per period:

$$C_0 = \sum_{t=1}^{N^*} NCF_t(1+i)^{-t} \tag{21}$$

Where C_0 is the initial investment cost, N^* is the payback period, NCF_t is the net cash flow of the project in year t and i is the discount rate as defined above.

4. EMPIRICAL STUDY

As a preliminary requirement of this study, parking lots that do not have enough slots to install solar panels are avoided in accordance with the calculations shown in Table 4.1.

Table 4. 1: Minimum required slot calculation.

DC charging station power	Required #of Panels	Required Area of the Panels (m^2)	Construction Flexibility (%10) Added (m^2)	Corresponding Area for Parking Slots (m^2)	Minimum Required Slots
360 kW	720	1,742.4	1,916.64	153.33	154
180 kW	360	8,71.2	958.32	76.67	77
120 kW	240	580.8	638.88	51.11	52

Three scenarios are analyzed for the power of the charging units: 120 kW, 180 kW and 360 kW, and 500-watt solar panels are chosen for the power generation. When the 500-watt solar panels on the market are examined, it is seen that panel dimensions are 1.1 m x 2.2 m on average. The dimension of each parking slot in Istanbul must be 1.5 m x 2.5 m for cars according to the Istanbul Parking Lot Regulation[3]. Table 4.1 shows the minimum required slot calculation for each of the scenario to eliminate the parking lots that do not have enough slots to install EVCS.

4.1. Data Sources

ISPARK has provided a data regarding all the parking lots that are open for public use. The main data set includes the following attributes for each parking lot for the year 2022: lot, parcel, direction, region, district, type, capacity, coordinates, area, annual total

[3] https://www.ibb.istanbul/BBImages/Slider/Image/otopark-yonetmeligi.pdf

number of parking, average number of daily parking, average parking time, parking tariff. Using the coordinates for each parking lot, photovoltaic power output and mean power density of the wind are obtained from Global Solar Atlas and Global Wind Atlas accordingly. Global Solar Atlas uses various sources to indicate solar related data globally, including Solargis. The data and the models were validated in 2019 through 228 public sites worldwide. Although validation of Global Wind Atlas data is still ongoing, it is the widest publicly available platform on wind which is constructed with historical data. Both works are funded by Energy Sector Management Assistance Program (ESMAP) which is administered by The World Bank Group.

When conducting the investment decision-making analysis, financial forecast metrics are obtained from The Economic Outlook for 2023 to 2033 in 16 Charts of Congressional Budget Office (2023)[4]. Data on the current EV outlook of Türkiye is gathered from Turkish Statistical Institute and Ministry of Industry and Technology's Mobility Vehicle and Technologies Road Map is used as a source for EV forecast for the years 2023, 2025 and 2030.

4.2.WEDBA Application

WEDBA method is chosen for this study because the parking lots that are closer to the optimum points are to be determined and the weights of the criteria can either be objective, subjective, or integrated. Considering the findings in the literature review and unique nature of installing photovoltaic charging station, decision factors and criteria that are affecting the site selection is determined. All the criteria used in the application are given in Table 4.2, which are all objective and treated as benefit type.

[4] https://www.cbo.gov/publication/58957

Table 4. 2: Details of evaluation criteria for the WEDBA problem.

Criteria	Explanation	Unit	Data Source
Photovoltaic Power Output (PVOUT)	The power produced per installed PV capacity unit per year. (On a coordinate basis)	kWh/kWp	Global Solar Atlas[5]
Mean Power Density of the Wind	It is the average annual available power per square meter of swept area for turbines and calculated at 10 m height above ground. (On a district basis)	W/m^2	Global Wind Atlas [6]
Capacity	Number of vehicles that can be accommodated in the parking lot.	Quantity	ISPARK
Area	The parking lot should have a certain area to install the PVCS and the possibility of expanding the capacity.	m^2	ISPARK
Total Number of Parking in 2022	Indicative measure for possible yearly demand.	Quantity	ISPARK
Average Number of Parking Per Day in 2022	Indicative measure for an average daily power demand for the PVCS.	Quantity	ISPARK
Average Vehicle Parking Time	Indicative measure for the possible length of use of charging units.	Minute	ISPARK
Parking Tariff (Full Day)	Supportive in terms of pricing and demand.	Turkish Lira	ISPARK

Initial investment cost is not added to the chosen criteria because the charging station to be installed is identical in each scenario of various powers, it is not a unique attribute to affect the decision.

To explain the calculation steps in detail, Eski Salı Pazarı parking lot for 120 kW is taken as an example and related calculations are shown in the below table.

Table 4. 3: Calculation steps of Eski Salı Pazarı for 120 kW in WEDBA problem.

[5] https://globalsolaratlas.info/map
[6] https://globalwindatlas.info/en

Original Criteria Values	Mean Power Density (W/m2)	Photovoltaic Power Output (kWh/kWp)	Capacity	Area	Total Number of Parking in 2022	Average Number of Parking Per Day in 2022	Average Vehicle Parking Time (min)	Parking Tariff (Full Day)
	56	1386,3	818	16304,05	702.688	1.925	4778	60
Standardized Values	-2,1590807	-63,448701	-0,52965	-0,375213	-0,5237892	-0,538082	-0,572726	-2,77849
ideal & anti-ideal points								
a*	215	1425,7	5028	296283,6	2440576	6686,51	4778	70
b*	39	1316,9	52	757,78	638	10,59	4	15
wj	0,0224542 3	0,0000277	0,1910227	0,2913756	0,1804312	0,1718051	0,1277400	0,0151436
WED +								
529411,999	-217,1591	-1489,1487	-5028,53	-296284	-2440576,5	-6687,048	-4778,573	-72,7785
WED -								
349,880125	-41,16	-1380,35	-52,53	-758,16	-638,52	-11,13	-4,57	-17,78
INDEX SCORE	0,000660448							

After obtaining the original criteria values for Eski Salı Pazarı, Equations 3, 8, 12, 14, 15, and 16 are used accordingly for each step shown in Table 4.3. Same calculations are made for all the parking lots for each scenario after filtering the parking lots according to the capacity need for solar panels.

4.2.1.WEDBA Results

Considering the potential solar energy productivity and the mean density of the wind, 5 parking lots are suggested for each of the 3 scenarios: 120 kW, 180 kW and 360 kW, and 500-watt solar panels are chosen for the power generation. After applying above methodology to the alternative set, below results in Table 4.3 are obtained:

Table 4. 4: Ranking of the parking lots obtained from WEDBA.

RANKING		
For 120 kW	**For 180 kW**	**For 360 kW**
Eski Salı Pazarı	Eski Salı Pazarı	Eski Salı Pazarı
Büyükçekmece Sosyal Tesisleri Arkası	Avcılar Meydan Açık Otoparkı	Avcılar Meydan Açık Otoparkı
Bostancı İDO Karşısı Açık Otopark	Sultanahmet Açık Otoparkı	Avcılar Denizköşkler Toplantı ve Davet Salonu Açık Otoparkı
Kartal Savarona Sahil Cep Otoparkı	Avcılar Denizköşkler Toplantı ve Davet Salonu Açık Otoparkı	Ortaköy Açık
Avcılar Meydan Açık Otoparkı	İspark West İstanbul Marina Açık Otoparkı	Kadıköy Açık Otoparkı

The results presented in Table 4.3 indicate that Eski Salı Pazarı comes as first to install a PVCS for various power alternatives. Since the values of PVOUT and mean power density of the wind data were very close to each other among the alternatives, it was observed that the criterion weights were low and did not significantly affect the result. The most outstanding attribute of the closest alternative to the optimum is that circulation is quite high in the sense of average number of parking per day along with average parking duration. Practically considering that the population density of the district Kadıköy (where this parking lot is located) is high during the day and it is in a central location, it seems quite consistent that this parking lot stands out in the results.

4.3. Investment Decision-Making

After obtaining from the results of WEDBA that Eski Salı Pazarı is the first ranked parking lot for each scenario of all 120 kW, 180 kW and 360 kW powered DC charging stations, potential EV parking and charging are analyzed with gathering data from various resources to determine the approximate number of EVs to park at Eski Salı Pazarı parking lot between the years 2023 and 2030 with corresponding yearly tariffs and approximate operating revenues.

According to Turkish Statistical Institute (2023), 23.32% of the total automobiles in Türkiye were registered in Istanbul in 2022. If the same ratio is applied for calculating the total EVs in Istanbul, it is observed that 0,1% of the total automobiles in Istanbul are EVs. 2022 data is chosen rather than a historical data because EVs were not very common

in Türkiye vehicle market in the previous years and therefore would negatively affect the forecast for future. The number of all automobiles in Istanbul is proportioned to the number of all types of vehicles (cars, pickup trucks, motorcycles) that can be parked in ISPARK parking lots, and the approximate proportional number of automobile parking is found by multiplying the annual number of parking in the Eski Salı Pazarı in 2022. This is multiplied by the approximate EV rate in Istanbul to find the annual proportional number of EV parking in 2022. Then, Ministry of Industry and Technology's forecasts (2022) which are shown in Table 4.4 are used for future years to approximately calculate EVs to park at Eski Salı Pazarı.

Table 4. 5: Ministry of Industry and Technology's EV stock projections.

Türkiye EV stock projection scenarios	**2025**	**2030**
Low	160,000	880,000
Medium	270,000	1,600,000
High	400,000	2,500,000

The data presented in Table 4.4 is then used to determine *k* factors for each scenario for the following periods: 2023-2025 and 2025-2030. With the *k* factors and ratios defined above, approximate number of EV parking at Eski Salı Pazarı is calculated and shown in Table 4.5.

Table 4. 6: Approximate number of EVs to park at Eski Salı Pazarı.

Years	**Low**	**Medium**	**High**
2023	1,174	3,908	6,316
2024	2,584	6,123	9,474
2025	5,684	9,592	14,211
2026	7,994	13,693	20,502
2027	11,242	19,545	29,579
2028	15,809	27,899	42,673
2029	22,232	39,823	61,565
2030	31,264	56,844	88,819

Approximate number of EVs to park at Eski Salı Pazarı are then used for calculating approximate revenues.

4.3.1. Benefit and Cost Assumptions

Market research has been made for each DC charging station with different powers and the approximate costs in the Table 4.6 have been reached for the installment and operation of the charging stations. It is assumed that rather than getting a network operator license directly from the T.R. Energy Market Regulatory Board, a dealership is obtained from a company that already has a license. Because the current regulation requires a license owner to install 50 charging stations in the following 6 months after getting the license.

Table 4. 7: PVCS installment and operation costs.

Costs	120 kW	180 kW	360 kW
Charging network operator dealership (annually)	Calculated as 20% of the revenues after deducting the project related capital expenditures.		
Using different brand name (annually)	$ 1,750	$ 1,750	$ 1,750
Charger installation	$ 22,500	$ 33,750	$ 67,500
Solar panels (500w)	$ 96,000	$ 144,000	$ 288,000
Micro wind turbine (7 kw)	$ 2,100	$ 2,100	$ 2,100
Rent cost per slot (annually)	$ 2,500	$ 2,500	$ 2,500
Management software	$ 11,000	$ 11,000	$ 11,000
Other (annually)*	$ 5,000	$ 7,500	$ 10,000

**This may include taxes and unforeseen expenses.*

It is assumed that technical support and services are provided by the licensee as in line with the market practice in Türkiye. When the current charging tariffs of 5 different charging networks are examined, it is observed that a fixed price is generally applied for 60 kW and above DC charging and the average is 0.4055 USD/kWh. This is due to the fact that high-power DC charging stations are not very common, since it has been observed that the tariffs at AC charging stations of different powers are different from each other. For this reason, in this study, the average DC charging fee, which is increased with inflation starting from 2024, has been accepted as the basis for 120 kW, and the tariff

has been increased by 10% as the power of the charging station increases. When making the price increases, projected overall inflation rates are used, and cashflow is discounted with projected federal funds rate as shown in Table 4.7.

Table 4. 8: Congressional Budget Office's projections.

	2023	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Projected Overall Inflation	3.3	2.4	2.2	2.1	2.0	2.0	2.0	2.0
Projected Federal Funds Rate	4.8	3.0	2.6	2.4	2.4	2.5	2.5	2.6

To calculate the NPV, IRR and DPP, projected inflation and federal funds rates are used from Table 4.7 for corresponding year. The cash flows are calculated with the assumption that, with 80% probability, the 100-kW battery vehicle will charge 60 kW.

4.3.2. Results

After gathering all data and using equations to calculate NPV, IRR and DPP as defined above, best performing values of the methods are obtained for low, medium, and high scenarios for each of the 120 kW, 180 kW and 360 kW photovoltaic charging stations as summarized in Table 4.8.

Table 4. 9: Financial indicators summary.

	IRR	**Discounted Payback Period (yrs)**	**NPV**
Low	120 kW	120 kW	180 kW
Medium	120 kW	120 kW	360 kW
High	120 kW	120 kW	360 kW

It is observed that if an investor wants to minimize liquidity risk, s/he should go with the decision of installing 120 kW PVCS in each scenario. But if the investor prefers to maximize economic return with taking the liquidity risk, s/he should go with 180 kW

PVCS in the low scenario and 360 kW in medium and high scenarios. Possibilities of each scenario are unknown since Ministry of Industry and Technology did not share the evaluations in detail in the report. The investor should conduct market research of his/her own and make the investment decision accordingly. The analysis could also be further expanded to include various methods.

5. DISCUSSION

The Eski Salı Pazarı parking lot, which was chosen according to the results of our multi-criteria decision-making problem, is a reasonable choice in practice as it is located in a densely populated area and has a high circulation during the day. However, the data provided by ISPARK only includes the year 2022. Calculations were made with only 2022 data in order to reduce the impact of COVID19 on the data, with 2020 being the pick point of COVID19. The solution of the WEDBA problem with multi-year historical data may yield different results. However, the result reached in its current state seems quite reasonable. It is not possible to make a precise prediction in the data related to solar energy and wind energy, the past data may be indicative, but it should be taken into consideration that there may be deviations in this regard.

On the other hand, the financial data used for investment analysis includes the predictions of the Congressional Budget Office. The number of electric vehicle stocks in Türkiye is also taken from the projections of the Ministry of Industry and Technology. Considering that there is always a margin of deviation in the forecasts, it should be taken into account that the investment scenario may also be affected. In this scenario of the investment analysis, it is seen that an investor who expects an economic return by reducing the liquidity risk should choose a 120 kW photovoltaic charging station. Investing with the consideration of liquidity risk seems reasonable for the investor, as all investments seem profitable in the long run.

6. CONCLUSION

Fossil fuel consumption is expected to be significantly decreased by the effect of electrification of the transportation sector. In parallel, the infrastructure of electronic vehicle charging stations should be planned effectively to meet the public charging demand when the use of electric vehicles increases. Especially in mega cities, where re-planning for urbanization is harder, transforming current parking lots in the most efficient way possible, can be a great opportunity as a local public service at municipal level. The purpose of this study is to investigate the existing parking lots of the IMM's subsidiary ISPARK in terms of their feasibility to install photovoltaic charging stations that have a micro wind turbine as a smart backup system. Considering the potential solar energy productivity and the mean density of the wind, 5 parking lots are suggested for each of the 3 scenarios. In line with the results of parking lot selection, economic feasibility of installing PVCS with various powers is analyzed from investment perspective with low, medium, and high scenarios.

6.1. Thesis Contribution

When the current electric vehicle charging station selection studies in the literature are examined, it is seen that the site selection for photovoltaic charging station studies is not very common. In addition, the application of the WEDBA method has not been encountered in studies where multi-criteria decision-making methods are used. However, the WEDBA method is a mathematical method that provides broad applicability to its practitioner in terms of attribute weights. It is a very effective method especially in problems where the optimum point can be determined. On the other hand, to the best of author's knowledge, PVCS site selection studies that also include evaluation from an investment perspective are not common. Considering all these, it can be stated that this study adds variety to the electric vehicle charging station location selection studies in the literature.

6.2. Limitations And Future Work

The most up-to-date data on solar and wind energy could not be reached, and the values in the sources reached were considered as approximate, especially for wind. Although it is not possible to reach certainty on the basis of coordinates with the information published by the official institutions of Turkey regarding these data, more recent approximate data may increase the accuracy of the presented insight. On the other hand, long-term forecasting studies of Turkey's official institutions on inflation and interest rate could not be found in open sources. The longest forecast reached is until 2025. For this reason, the investment analysis had to be made in US dollars. If these data were available, investment analysis could be done in the local currency. Further analysis can be done by adding more attributes to the MCDM problem, using different methodologies for both site selection and investment analysis. Also, this analysis can be applied to different cities in Türkiye.

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APPENDICES

Appendix A. Cash Flows for each scenario**.**

CASH FLOWS ($)	2023	2024	2025	2026	2027	2028	2029	2030
120 kW								
Low	(117,236)	33,087	86,008	127,508	186,994	272,403	394,999	570,936
Medium	(62,273)	91,376	151,794	225,449	332,555	488,584	715,845	1,046,819
High	(13,858)	146,576	229,542	342,490	508,455	752,771	1,112,386	1,641,673
180 kW								
Low	(178,986)	34,782	92,961	138,576	203,977	297,893	432,713	626,208
Medium	(124,023)	98,901	165,326	246,311	364,094	535,691	785,644	1,149,679
High	(75,608)	159,621	250,847	375,056	557,584	826,297	1,221,839	1,804,018
360 kW								
Low	(359,236)	36,904	100,870	151,017	222,930	326,209	474,482	687,297
Medium	(304,273)	107,434	180,472	269,526	399,059	587,788	862,705	1,263,115
High	(255,858)	174,226	274,546	411,145	611,898	907,454	1,342,520	1,982,888
i	3.3%	2.4%	2%	2%	2%	2%	2%	2%

Appendix B. Financial indicator values for each scenario.

Scenario	IRR	DPP (yrs)	NPV
120 kW			
Low	81%	3,02	$ 1.366.669
Medium	202%	1,70	$ 2.648.536
High	1113%	1,10	$ 4.189.116
180 kW			
Low	65%	3,43	$ 1.442.323
Medium	130%	2,17	$ 2.846.880
High	264%	1,49	$ 4.536.677
360 kW			
Low	42%	4,42	$ 1.414.961
Medium	75%	3,11	$ 2.954.478
High	114%	2,33	$ 4.808.412

BIOGRAPHICAL SKETCH

Serra Mandacı was born in [redacted]. She completed her high school education at Maltepe Gökyüzü Science High School. She graduated from Istanbul Şehir University Industrial Engineering undergraduate program with a minor in Computer Science and Engineering program in 2019. Since 2020, she has been working at the Istanbul Metropolitan Municipality as part of the external financing team at Directorate of Finance. She contributed cross border structured finance transactions of many municipal infrastructure projects. She is working in project finance with products such as ECA covered loans, commercial loans, and bonds.

PUBLICATIONS

Mandaci, S., & Tolga, A. Ç. (2023, August). Site Selection of Solar Powered Electric Vehicle Smart Charging Station: Istanbul Case. In *International Conference on Intelligent and Fuzzy Systems* (pp. 676-683). Cham: Springer Nature Switzerland.