Fırat Üniversitesi Müh. Bil. Dergisi
37(1), 423-432, 2025

Araştırma Makalesi
https://doi.org/10.35234/fumbd.1603738

Electricity Consumption of Electric Vehicles in Türkiye and its Share in Total Electricity Consumption: 2030 Projection

Habip SAHIN[1*]
Department of Electricity and Energy, Fırat University, 23119, Elazig, Türkiye
*habipsahin@firat.edu.tr

(Geliş/Received: 18/12/2024; Kabul/Accepted: 03/02/2025)

Abstract: The rapid expansion of electric vehicles (EVs) and the accompanying increased demand for electricity will put a huge burden on the electrical system. In this paper, the electricity consumption of EVs is analyzed by using realized data and is forecasted for near future. The weighted average value of rated consumption for EVs in Turkish market is found to be 175 W/km. Until 2030, it is estimated that electricity consumption will increase by 2.5% annually on average. It is predicted that the electricity consumption shares of EVs in general consumption, which was 0.03% for 2023, will increase to 0.64% by 2030. Based on these findings, Türkiye should turn to renewable and sustainable energy sources and support renewable-supported smart charging systems to meet increasing demand for electricity in a more environmentally and economically sustainable manner.

Key words: Electric vehicles, Electricity, Electricity consumption, Electricity generation.

Türkiye'de Elektrikli Araçların Elektrik Tüketimi ve Toplam Elektrik Tüketiminde Payı: 2030 Projeksiyonu

Öz: Elektrikli araçların hızlı yayılımı ve buna eşlik eden artan elektrik talebi, elektrik sistemine büyük bir yük getirecektir. Bu çalışmada, elektrikli araçların elektrik tüketimi geçmiş veriler kullanılarak analiz edilmiş ve yakın geleceğe yönelik tahminlerde bulunulmuştur. Türkiye pazarındaki elektrikli araçlar için ortalama ağırlıklı tüketim değeri 175 W/km olarak bulunmuştur. 2030 yılına kadar elektrik tüketiminin yıllık ortalama %2,5 artması beklenmektedir. 2023 için toplam tüketimde %0,03 olan elektrikli araçların elektrik tüketimindeki payının, 2030 yılında %0,64'e yükselmesi öngörülmektedir. Bu bulgulara dayanarak, Türkiye'nin artan elektrik talebini daha çevre dostu ve ekonomik olarak sürdürülebilir bir şekilde karşılayabilmesi için yenilenebilir enerji kaynaklarına yönelmesi ve yenilenebilir destekli akıllı şarj sistemlerini desteklemesi gerektiği sonucuna varılmıştır.

Anahtar kelimeler: Elektrikli araçlar, Elektrik, Elektrik tüketimi, Elektrik üretimi.

1. Introduction

Supply and sustainability of energy are very significant and vital for all countries, also local and global environmental effects of energy consumption is another important issue. Although, to reduce these effects, precautions are taken at both worldwide and local scales, emissions from energy production and consumption recovered in 2023 to reach highest annual level ever [1]. Shifting from conventional vehicles based on fossil fuels to green fuel vehicles using electricity or hydrogen will make excessive contributions to decrease the environmental effects [2]. To promote this trend, electric vehicles (EVs), having higher cost than conventional ones, are supported [3]. In Türkiye, the tax for special consumption (SCT) applied to EVs ranges from 10 to 60%, while these values are between 45% and 220% for conventional vehicles [4].

In the literature, various studies have been conducted on the EV market and EV infrastructures in Türkiye. Tunçel examined the attitudes and purchase intentions towards EVs among Turkish consumers [5]. In this study, in an emerging market, a new personal antecedent of EV purchase intention is revealed by observing the influence of various aspects of motivated consumer innovativeness with an emphasis on the consumer perspective. Gönül and et al. illustrated a framework of position of Türkiye in EV technologies by evaluating the current EV stock and infrastructure of charging stations, as well as regulations, research and development activities about EVs. [6]. It was concluded that acceptance of EVs in Türkiye is low compared to developed countries, and therefore social awareness about electric vehicles should be increased. In their study conducted in 2024, Çetin and Taşdemir estimated the electric vehicle sales in Türkiye for the following 2 years with the optimized SARIMA model [7].

* Habip Sahin: habipsahin@firat.edu.tr ORCID : 0000-0002-0907-2022

According to their results, a steady upward trend in EV sales was predicted, with sales projected to be around 96,076 units by January 2024, 108,559 units in July 2024, and 100,676 units in December 2025. Ağbulut improved different artificial intelligence algorithms to forecast energy demand up to 2050 for the transportation sector in Türkiye [8]. It was forecasted that the annual growing rate of energy demand would be 3.7%. In this study, EVs were not specifically mentioned in the aspect of electricity consumption, but an overall analysis was made for the transportation sector. Ünal analyzed electricity consumption using artificial neural network methods [9]. As a result of the study, it was determined that the best result was obtained by obtaining the RMSE value of 0.0157 and the R value of 0.9976, which were taken as the performance measure of the 2-layer feedforward backpropagation neural network. Pala estimated electricity consumption in Türkiye using time series [10]. The research examined Türkiye's per capita electricity consumption between 1965 and 2022, utilizing both deep learning and statistical models for forecasting. The TBATS model emerged as the most effective in producing accurate predictions. The findings indicate a consistent increase in electricity consumption per individual over the years. Therefore, developing energy policies that prioritize sustainability, environmental conservation, and energy security was essential. Gençer and Bediroğlu examined the relationship between electric vehicle sales, carbon emissions and electricity consumption [11]. According to the results obtained, a cointegration relationship was found between electric vehicle sales and electricity consumption. In line with these results, FMOLS Fourier Cointegration coefficient estimate was calculated. Burunkaya and Demirkol analyzed the effects of increasing usage of EVs on the electricity distribution network for Türkiye [12]. It was observed that EV charging creates a serious fluctuation and load profile in terms of the distribution grid, in peak hours. Coban and et al. examined EV-Grid interaction for Turkish electricity system [13]. By applying the proposed algorithms, it was shown that optimal bi-directional V2G effects are important in distribution systems with high penetration of EVs. It was revealed that by applying such solutions in the field of electromobility, energy system stability and energy independence can be achieved by obtaining the desired synergy effect. Coban and et al. conducted research on estimating energy consumption of EVs [14]. The study provided a scaled estimate of EV home charging in Türkiye, concluding that an average EV adds 3.1 kWh per day to the overall household load, well below the amount assumed by grid regulators. Ekici et al. studied on EVs, electric vehicle charging systems and the current status of charging infrastructure in Türkiye [11]. The study conducted a comprehensive review of worldwide electric vehicle charging systems within the framework of electric vehicles, charging stations, installations and implementation of standards in Türkiye. The distribution of charging stations in Türkiye was analyzed in terms of location, region, type, infrastructure requirements and future projections.

In this paper, the bidirectional interaction between EVs and electrical energy is examined in detail. With the increasing usage of EVs, it places a great burden on electricity consumption, which is used as an energy source, and therefore on power grid. In this respect, Türkiye's electricity generation and consumption data is examined and estimated until 2030. It is one of the few studies in the literature in which this distinction is made. In the literature, the relationship between electric vehicles and electricity consumption in Türkiye has not been clearly quantified. In this study, the electricity consumption of electric vehicles and their direct share in total electricity consumption are calculated for both past and future years. Additionally, by separately analyzing electricity generation and consumption while accounting for inefficiencies in transmission and distribution, this study contributes to the existing body of literature. This study is one of the first to identify the sales figures, types, and consumption patterns of EVs in the Turkish market and to project their widespread adoption by 2030.

2. Material and Methods

Annual intensity of consumed electricity and sales of EV s in Türkiye are estimated until 2030 by using Autoregressive Integrated Moving Average (ARIMA) technique to reveal the electricity consumption of EVs in operating conditions and its share in total consumption. Therefore, this method is applied for time series data of sales figure of EV s and total electricity generation and consumption.

ARIMA is derived from the autoregressive model (AR), the moving average model (MA), and ARMA models, combination of AR and MA [16]. In order to use the ARIMA model, the time series must be stationary and there must be no missing data. To set up the ARIMA model, MINITAB statistical software package is used. The mean-square error (MS), is used to check the accuracy of the fitted model. Although the MS is not very informative by itself, it can be used to compare accuracy of different ARIMA models [16]. Generally, smaller values of the MS specify a more suitable model.

In this study, ARIMA (1,2,2) model, which is used to estimate EV sales figures until 2030, is an important parameter that affects all other results of the study. The expression of the general ARIMA(p,d,q) pattern is shown in Eq. 1 [17].

$$\left(1-\phi_1 B-\cdots-\phi_p B^p\right)(1-B)^d y_t=c+\left(1+\theta_1 B+\cdots+\theta_q B^q\right)\varepsilon_t \tag{1}$$

where,p is order of the autoregressive part, d is degree of first differencing involved, q is order of the moving average part, ϕ, θ are parameter constants, B is notation for backshift and ε_t denotes white noise.
If the equation for general ARIMA (1,2,2) is rewritten (Eq. 2);

$$(1-\phi B)(1-B)^2 y_t=c+(1+\theta_1 B+\theta_2 B^2)\varepsilon_t \tag{2}$$

Table 1. ARIMA models can be estimated with EV sales data and the parameters of the models.

Parameters	(0,2,1)	(0,2,2)	(1,2,1)	(1,2,2)
ϕ_1			0.182	-0.11
θ_1	0.811	0.625	0.823	0.76
θ_2		0.214		0.8
c	4142	3897	3356	3587
MS	$4.34*10^8$	$4.39*10^8$	$4.76*10^8$	$3.44*10^8$

The ARIMA models are determined to be ARIMA (1, 1, 3) for electricity generation, ARIMA (1, 1, 4) for total electricity consumption, ARIMA (1, 2, 2) for EV sales and ARIMA (0, 1, 3) for average mileage per year.

2.1. Electricity generation and consumption in Türkiye

ARIMA models are created using datasets, provided from Türkiye Elektrik İletim Dağıtım Anonim Şirketi (TEİAŞ), for electricity generation between 1993 and 2023. In the light of these datasets, the amount of electricity that will be generated and consumed are estimated for the years from 2024 until 2030 with the ARIMA (I, I, 3) and ARIMA (I, I, 4) models, respectively. Since there is no nuclear power plant (NPP) currently in power production in Türkiye, data on nuclear are not available.

The realized and forecasted data is given in Fig.1 together for the years between 2010 and 2030. When the electricity generation and consumption are considered after 2010, it can be seen in Fig.1 that both generally increase except for the years 2019 and 2022. In these years, although the decline in generation was more obvious, the decline in consumption was very limited. The reason for this decline is due to Türkiye's economic reasons rather than the pandemic covering 2020 and 2021. The electricity generation for 2010 and 2023 is 211,207.7 GWh and 331,148.9 GWh, respectively and it is estimated to be 399450.4 GWh in 2030. The electricity consumption for 2010 and 2023 is 172,050.6 GWh and 289,371.7 GWh, respectively and it is estimated to be 345828.9 GWh in 2030. The consumption value for the first 11 months of 2024 is 317501.8 GWh, and when the estimated December is added, it corresponds to a value of approximately 347000 GWh [18]. According to the forecast model, production for 2024 is estimated to be 338453.8 GWh. This shows that the accuracy rate of the model is 97.54%.

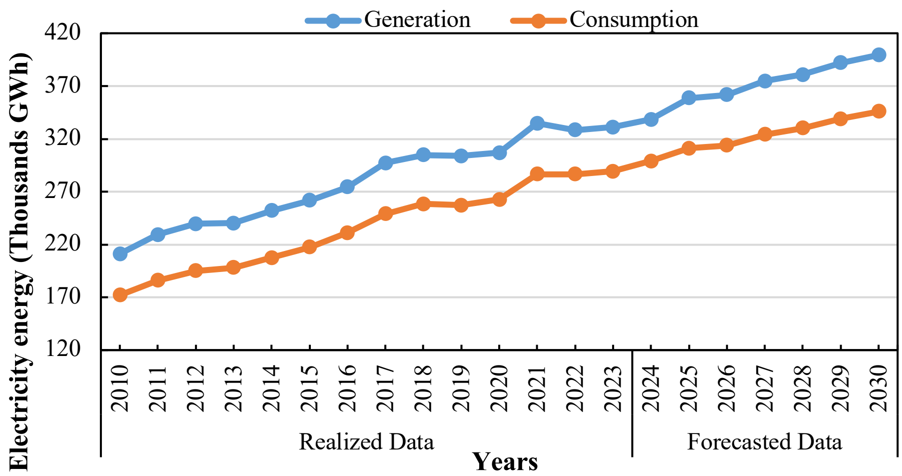

Figure 1. Realized and forecasted electricity generation and consumption from 2010 to 2030.

2.2. Turkish electric vehicle market

EV sales in Türkiye officially started in 2012 and two kinds of taxes are collected on the EV sale, first one is Value Added Tax (VAT) and second one is Special Consumption Tax (SCT) [19]. The value of VAT was applied as 18% until July 2023, but as of this date it has been increased to 20% [20]. SCT was applied up to engine power as 3%, 7% and 15% for under 85 kW, 86-120 kW interval and over 121 kW until 202, respectively [21]. In 2021, rates were reassessed to 10%, 25% and 60% respectively for the same intervals [22]. In July 2022, in addition to engine power, tax base criterion was also added to the determination of SCT. With this change, SCT was determined as 10% for EV s having an engine power under 160 kW and tax base under 700,000 ₺; 40% for tax base is over 700,000₺; 50% for those having an engine power over 160 kW and tax base under 750,000 TL; 60% for others [23]. In 2023, the tax base criteria was updated to 1,250,000₺ and 1.350.000₺, respectively [24]. With the last update made at the end of 2023, the value of 1,250,000₺ has been updated to 1,450,000₺ [25]. EVs are divided into three groups, the first one is pure or battery electric vehicles (BEV), the second one is extended range electric vehicle (EREV) and the final one is plug-in hybrid electric vehicles (PHEV). Since EREVs do not cause electricity consumption, they are outside the scope of this study. BEVs constitute the overwhelming majority of EV sales in Türkiye. EV sales varied in the interval of 2012 and 2019 and had not shown much progress (Fig. 2). There is a logarithmic increase in sales after 2016. I Although, sales figures quadrupled almost every year between 2019 and 2023, the share of EV sales in the light commercial vehicle (LCV) market, including passenger cars, was able to exceed the 1 % threshold, reaching 1.3% in 2022 [26]. The increase in sales figures has slowed down in the last year, and for the first ten months, the sales figure of 2024 is 50.8% higher than in 2023 [27].

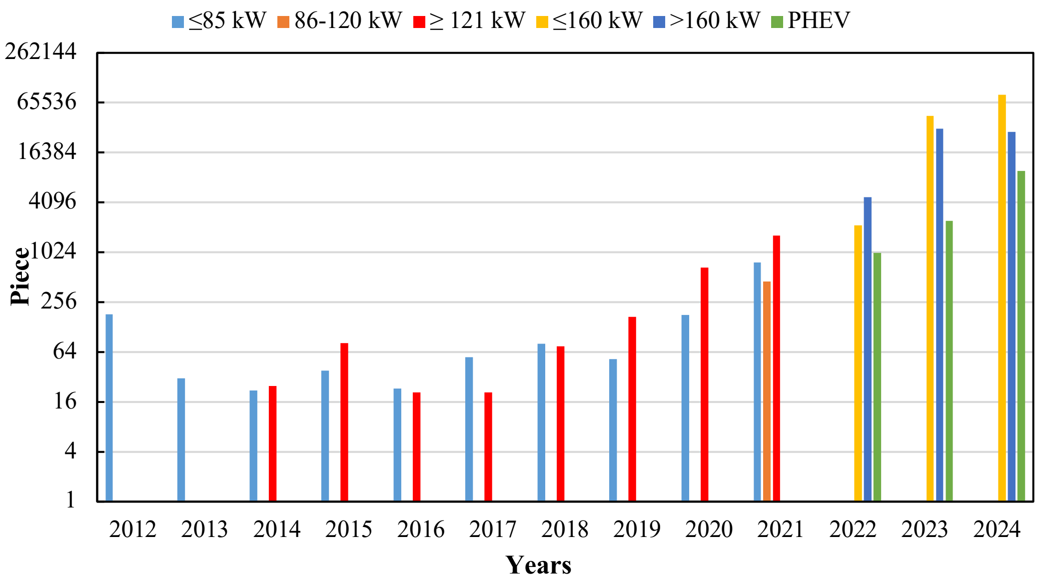

Figure 2. Annual sales volume of EV between 2012 and 2024 in Türkiye [28].

Sales data between 2024 and 2030 were estimated with the ARIMA (1,2,2) model using EV sales data from 2012 to 2023, and the results are shown in Fig. 3. Considering the problems in vehicle supply chain throughout the world after the pandemic and that TOGG will only be supplied to the domestic market in the first years, the introduction of a domestic electric car for sale in the Turkish market, where the demand for EVs has increased considerably in recent years, will increase this demand even more [29,30].

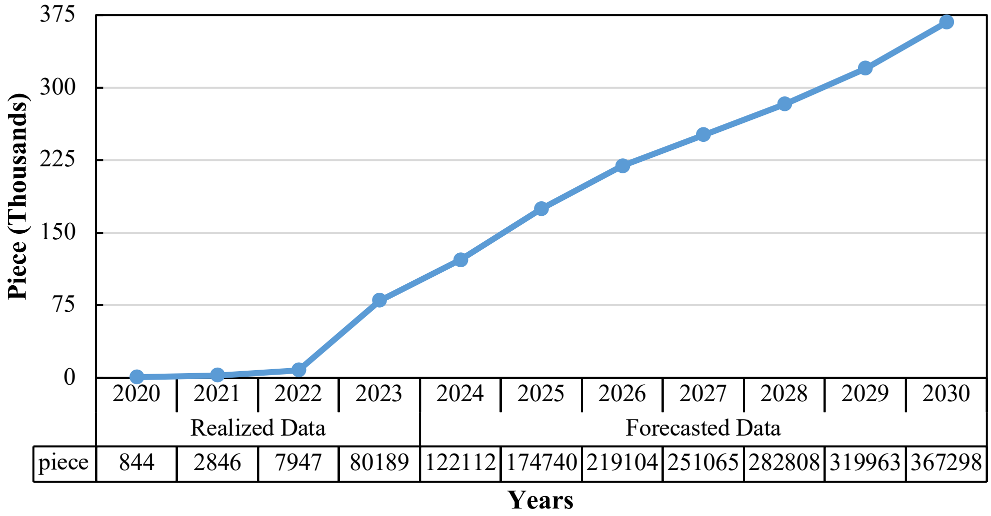

Figure 3. Realized and forecasted values for annual sales volume of EV between 2020 and 2030 in Türkiye.

The total number of EV sales in 2023 reached 80,189 pieces and it is 120,944 for 2024 [28]. It is estimated that this number will reach 367,298 in 2030. Considering that the annual electric vehicle sales volume for 2024 are predicted to be 122,112 units according to the forecast model, it is seen that an accuracy rate of 99.04% is achieved.

2.3. Electricity consumption of electric vehicles in Türkiye

To calculate total electricity consumption of EVs, it is essential to first establish the energy consumption values for EVs. Typically, EVs have two types of consumption values: rated consumption (RC) and vehicle consumption (VC). RC, including charging losses, is the official figure provided by the companies, while VC represents the battery energy consumed while driving. The RC values, based on the Worldwide Harmonized Light Vehicles Test Procedure (WLTP) Class 3 for EVs available in Türkiye, are used. In Table 2, RC and VC values and sales figures are specified for top 10 EV brands in Turkish market for 2023.

Table 2. Rated and vehicle consumption values and sales figures of EVs on sale in Turkish market in 2023 [31].

Vehicle model	Pieces	Rated consumption (Wh/km)	Vehicle consumption (Wh/km)
TOGG T10X	19583	191	169
Tesla Model Y	12150	169	140
Renault Megane E-Tech	2892	161	137
MG 4	2842	163	140
Skywell ET5	2541	172	156
Citroen e-C4	1881	149	122
Opel Corsa e	1777	158	131
Renault ZOE	1772	174	132
Opel Mokka e	1757	160	138
Dacia Spring	1483	145	114
Weighted average	-	175	150

The weighted average (WA) values for rated and vehicle consumption are calculated by Eq.3 [32].

$$\mathrm{WA} = \frac{\sum(v_i * CV_i)}{\sum v_i} \tag{3}$$

where v_i is number of each brand, CV_i is consumption value of each vehicle. Based on the sales and consumption data for EVs, the values are calculated as 175 Wh/km for RC and 150 Wh/km for VC as weighted average. The annual mileage of EVs are also considered to calculate the total consumption of EVs. Based on these calculated values, predictions are made until 2030. For the years between 2016 and 2022, TURKSTAT published annual average mileage of LCVs. From 2016 to 2022, these values are given as 13117, 13107, 13776, 13325, 12474, 13048 and 13415 km/year, respectively [33]. However, these values are not given separately for EVs. Considering that they are preferred especially for shorter distances due to range concerns and difficulty in finding a charging station, and they are not preferred especially for long intercity trips, their annual average kilometers will be less than traditional vehicles. Davis determined that the average annual mileage of EVs is 61.8% of that of conventional ICEVs [34]. In the light of this data, in this study, the average annual mileage values of EVs are taken as 61.8% of the values given by TURKSTAT and are determined using the ARIMA (0, 1, 3) model for the forecast years (Fig.4).

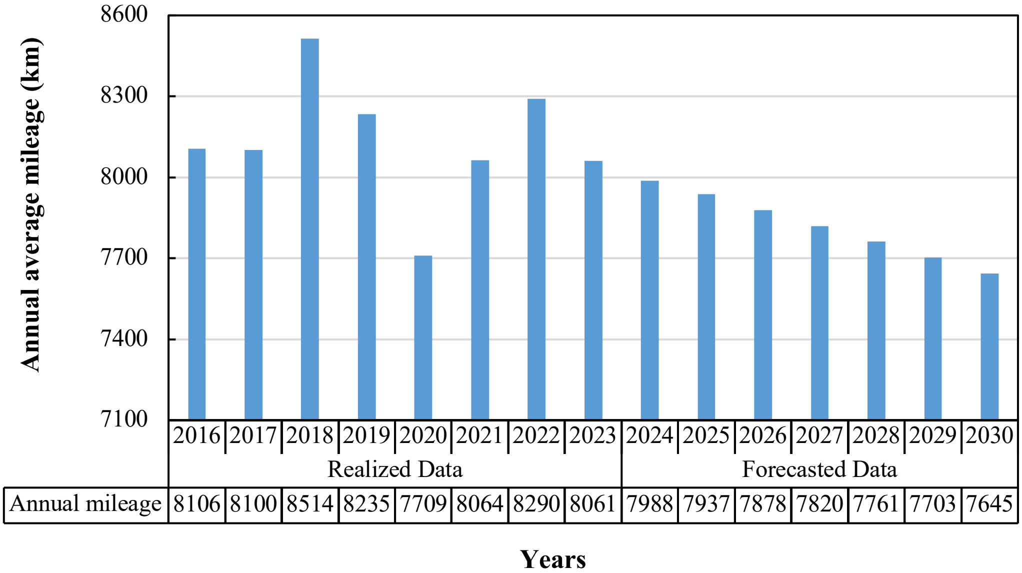

Figure 4. Realized and forecasted values for annual average mileage of EVs.

3. Results and Discussion

As EV usage grows, a key issue will be the electricity consumption of EVs and the capacity to supply the rising demand. To estimate the annual consumption of EVs, sales data, average mileages, and calculated weighted average RC values are used. Determining the annual consumption by EVs requires first calculating the number of vehicles in that year. The effective number of EVs for each year is determined by summing sales from earlier years and adding half of the current year's sales, assuming consistent sales distribution (Eq.4) [35]. The total consumption of EVs for a year is then found by using Eq.5 [35].

$$\mathrm{N_{eff,i}} = \sum n_{i-1} + n_i/2 \tag{4}$$

$$\mathrm{E_{c,i}} = \mathrm{N_{eff,i}} \times \mathrm{RC} \times \mathrm{M} \times 1GWh/10^9Wh \tag{5}$$

where $N_{eff,i}$ is effective number of EV and n_i is sales figures of EV for the year i. $E_{c,i}$ is consumption of EV for the year i and M is annual mileage. Realized and forecasted values for annual total mileage and cumulative number of EVs are given in Fig. 5.

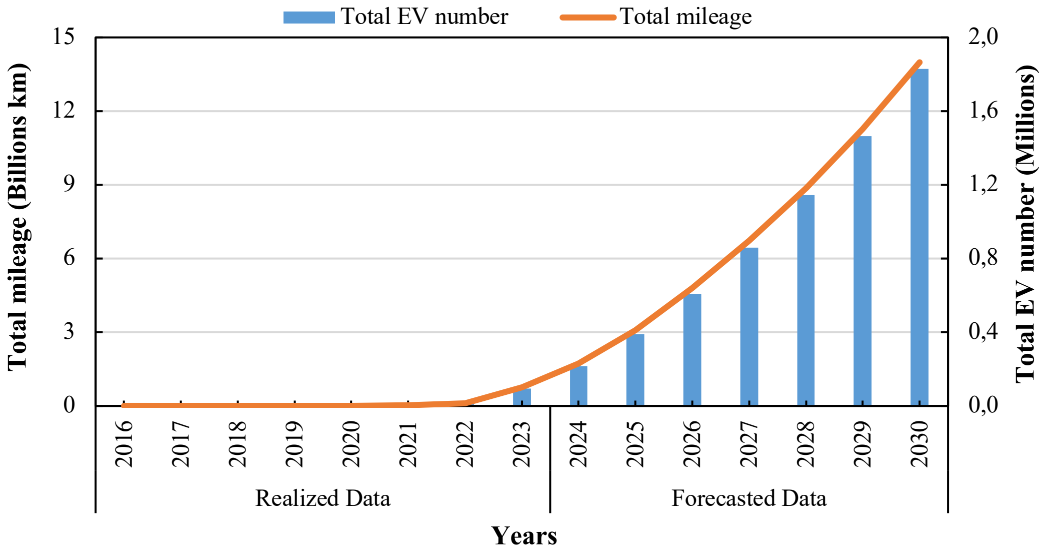

Figure 5. Realized and forecasted values for annual total mileage and cumulative number of EVs.

While the number of LCV type electric vehicles currently registered in traffic is around 170 thousand, it is estimated that this number will exceed 1 million in 2028 and1.8 million in 2030. Calculated and estimated annual electricity consumption values of EVs and their ratio to total consumption values are given in Fig. 6.

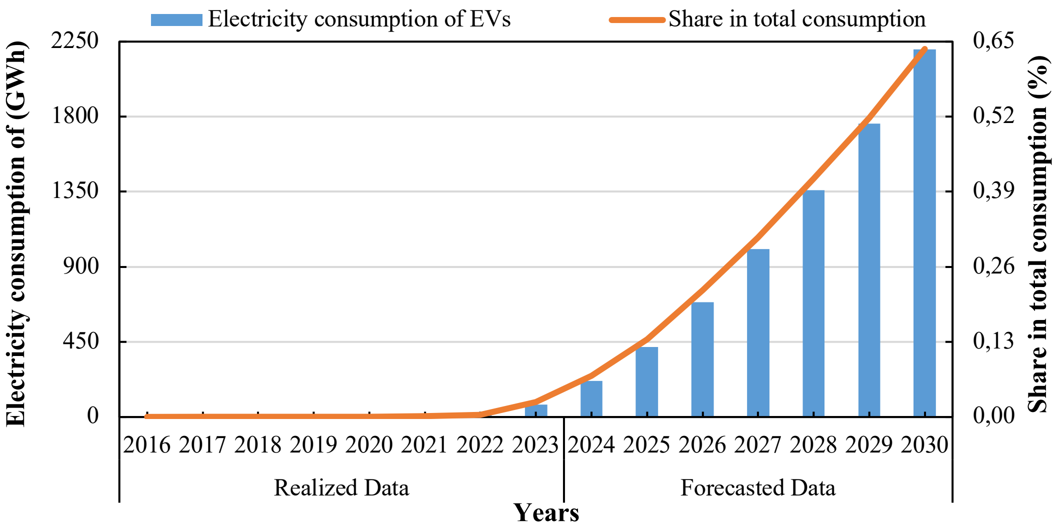

Figure 6. Annual electricity consumption of EVs and its share in total consumption in Türkiye.

Despite the rapid and significant increase in the number of EVs and the associated electricity consumption, the share of EVs in total electricity consumption remains very low. In 2023, the effective number of vehicles is around 50 thousand and EV-related electricity consumption is calculated as 74.3 GWh. This value corresponds to only 0.03% of the total consumption of 289371.7 GWh. It is estimated that the effective number of EVs will be around 1.65 million in 2030 and the electricity consumption from EVs will be 2203.9 GWh. Considering that the total electricity consumption for the same year is estimated as 345828.9 GWh, thus, only 0.64% of the total consumption will be realized by EVs.

Türkiye’s installed electricity generation capacity has grown annually, reaching 110,914 MW by 2023, with a utilization factor of 48.8% based on theoretical operating hours. [36]. These values actually mean that Türkiye will not face major problems in terms of generation infrastructure in meeting the increasing electricity demand. The resources used as primary energy sources in the electricity generation to meet the rapidly increasing demand in an environmentally friendly and sustainable manner are also of great importance. The renewable energy installed capacity in Türkiye has consistently grown each year, reaching 63,160.6 MW in 2023, with its proportion of the total installed capacity rising to 56.9% [37]. Although renewables accounted for 56.9% of installed capacity in 2023, their share in actual generation was 42.3%, reflecting a significantly lower utilization factor. This discrepancy is due to the variability of renewable energy sources (RES), which fluctuate by year, season, and even time of day. Meeting the increasing demand with RES is also of great importance in terms of domestic resource use for Türkiye, which is poor in terms of fossil fuel resources. Switching to non-renewable sources will raise the emission intensity of electricity consumption, leading to higher emissions associated with EVs and dependence on foreign energy. This situation is not sustainable both environmentally and economically for Türkiye.

Another concern is that the electric power demand from EV usage will be unevenly distributed, with higher demand in densely populated areas. As a result, even if the overall installed capacity is adequate, the existing grid infrastructure may struggle to support demand in these high-density regions. The most effective and rapid solution to address this issue is the implementation of smart charging systems. Smart charging helps manage the increased energy demand by shifting loads away from peak hours, thereby reducing strain on the power grid. More sustainable outcomes can be achieved by combining smart charging systems with renewable energy sources [38]. With smart charging applications, charging costs and operational cost of grid can be decreased by l0% to 30% [39]. In Türkiye, which is very rich in renewable energy resources, smart charging systems can be backed by wind and solar energy, allowing for a smoother adaptation to the rapid growth of EVs and effectively addressing potential challenges. While no extra load is created on the power grid with solar energy during peak hours, wind energy, whose surplus cannot be utilized with the decreasing electricity demand at night, can also be brought into the economy.

4. Conclusion and Policy Implications

With this study, it is estimated that the number of EVs will increase expressively over the next decade. As the number of registered vehicles increases, the electricity consumption of EVs will also increase. As a result, it becomes important to estimate the potential electricity consumption demand and its impact on the electricity grid in order to ensure the stability of the nationwide energy system. As rising energy demand will greatly impact the current electricity system, the government will must to adapt by expanding generation capacity and grid to supply this demand. This issue will attract more and more attention as Türkiye will produce its domestic EV. Enhancing grid capacity is crucial not only for maintaining endurance and security of the electricity supply but also for minimizing losses occurring in transmission and distribution. On the electricity generation side, the important issue is the main sources to be used to meet this significant increase and the emission intensities of these resources. RES should be the first choice here, as they are both more sustainable and more environmentally friendly.

Given Türkiye's potential, utilizing RES is crucial for reducing both greenhouse gas emissions and reliance on foreign energy. Due to their high capacity for consistent output and low emissions, nuclear power plants may be considered a secondary priority. This study offers some important implications for future research in order to make a more detailed forecast of the rapidly growing EV market and the resulting increase in electricity demand. With EVs gaining a significant place in the market, clearer feedback can be obtained and thus research will be able to provide more precise estimations. The resolution of the forecasts, currently made on an annual basis, can be increased by analyzing the driving and charging patterns of EV owners.

The weighted average consumption data for EVs are calculated as 175 Wh/km for RC and 150 Wh/km for VC. This study presents a projection for 2030. It is estimated that annual sales of electric vehicles will reach 367 thousand and the number of electric vehicles in traffic will reach 1.8 million in 2030. It is estimated that electricity generation will increase to 400 thousand GWh and consumption to 346 thousand GWh, and the share of electric vehicles in total consumption will increase to 0.64% in 2030.

The future scope of this study is to support modeling with artificial intelligence so that variables that depend on many parameters such as electricity production and consumption can be made more accurately.

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