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Article

Electric Vehicles and Vehicle–Grid Interaction in the Turkish Electricity System

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Abstract: Electric vehicles and energy storage systems are technologies in the stage of intensive development. One of the innovative ways to use electric cars is the Vehicle to Grid (V2G) concept. V2G charging points are characterized by the ability of bidirectional energy flow while charging EV/BEV (Electric Vehicles/Battery Electric Vehicles). In periods of low energy consumption and the presence of the highest shares of renewable sources, the cleanest electricity is drawn from the grid at the lowest prices and stored in a "mobile warehouse", which is an electric car. During the reported peaks in electricity demand and the presence of high tariffs, the previously stored energy may be sold back to the distribution network operator. Thanks to this application, the technology determines the highest profitability of the system and assigns EV/BEV the ability to manage electricity flows, while improving the energy balance of the economy. The prospects for the spread of V2G have increased along with the growing requirements for domestic economies, closely related to the significant share of renewable energy sources. The vision of connecting EV/BEV with the power grid creates completely new ways of managing energy and makes it possible to build smart agglomerations in line with the Smartcity idea. Especially since Turkey is one of the countries promoting this idea. The scientific aim of the study is to maximize the aggregator's profits for V2G by creating a coalition with renewable energy producers and combining the capacities of many EVs and offering their total capacities to the electricity markets. The subject of the research was to obtain extensive knowledge about the vehicle–grid interactions taking place in the Turkish power system. For this purpose, an analysis is conducted to determine the optimal preferred operating points and the amount of regulation proposals that maximize the profit of the EV users while satisfying the constraints of each stochastic parameter. The results show the system benefits from the implementation of the algorithms are significant to optimal bidirectional V2G impacts on distribution systems with high penetration of EVs. The research can find practical applications in assessing the role of electric vehicles and their integration in the vehicle–grid system in power systems. At the same time, pointing to the benefits related to the implementation of such solutions for Turkey and other countries in the field of electromobility, stability of energy systems, and energy independence through the possibility of achieving the desired synergy effect.

Keywords: electromobility; smart technologies; vehicle to grid; power system; energy independence

1. Introduction

Exploitation of fossil fuels at the expense of the environment has led to the development of research in areas focusing on issues related to renewable energy sources, the idea of electromobility, and energy independence [1]. The main problem with renewable energy sources such as wind and solar energy is fluctuation in the amount of electricity supplied to the grid [2]. To overcome the irregularity of renewable energy, it is necessary to store energy that can be used when needed. One solution comes from an unexpected source, EV/BEV [3,4]. In particular, the impact of vehicles plays a very important role in the emission of harmful gases causing increasing environmental pollution [5]. Transport and electricity generation contribute to most of these CO_2 emissions. Recently developed high-capacity battery systems are starting to play a very important key role in reducing carbon dioxide emissions through the electrification of transport and solving the problem of variability of renewable energy. Considering that, as other researchers emphasize, about 65% of world oil consumption is consumed in the transport sector [6,7]. Consequently, most of the used vehicles are conventionally powered ICE vehicles. The road transport sector alone is responsible for 23% of all CO_2 emissions [8]. At this stage of consideration, it should be emphasized that in the road transport sector, due to the increasing greenhouse gas emissions with the intensive use of fossil fuels, alternative solutions instead of conventional vehicle technologies have become fast pace. Currently, research is conducted on various types of drives, such as HEV, PHEV, BEV, and FCEV [9–13]. Electric vehicles have become one of the most popular research topics in recent years due to the increase in capacity and range of batteries and the decline in battery prices [14–16]. In this direction, many countries apply a policy of incentives to increase the number of electric vehicles [17,18]. According to the International Energy Agency's Electric Vehicle Research Report, the total number of electric vehicles will reach 245 million by 2030 [19]. With the increasing use of electric vehicles instead of fossil fuel-powered vehicles in the transport sector, the aim is to reduce fuel costs and gas emissions as low as possible. The available literature emphasizes that electric vehicles can not only increase the use of clean energy and reduce gas emissions but also improve the safety and economy of an appropriate energy system by coordinating with variable renewable energy sources such as wind and sun. It can also be considered a storage facility for the grid, and Vehicle-to-Grid Charging Stations (V2G) can also be used to service the grid during peak load periods [20].

According to the report of the European Alternative Fuels Observatory, the number of electric vehicle charging stations in Turkey at the end of 2021 amounted to 3457, which is an increase of 48% compared to the previous year [21]. As a result, Istanbul ranks first with 1265 units and hosts 37% of all electric vehicle charging points in Turkey [22]. Depending on the specifications of the charging station and vehicles, the charging time for electric vehicles can vary from ten minutes to several hours. The load on electric vehicles increases the pressure on the grid, causing adverse effects on distribution systems. Especially fast charging stations with high power consumption have a much greater impact on the network. V2G is one of the smart grid technologies that use the storage capacity of electric vehicles to improve the performance of the electricity system [23]. Moreover, V2G enables energy exchange between EVs and the power grid, which has the potential to support the grid in many ways [23].

On this basis, the authors support the ferry thesis by one of the researchers that electric vehicles not only reduce harmful emissions but can also help stabilize the power grid thanks to a proven, reliable technology called vehicle–grid [24]. Rather than simply drawing energy from the grid, V2G allows the vehicle's battery to store energy, including renewable energy, and then safely return some of that energy back to the grid when it is needed the most. With V2G, a fleet such as electric buses can be recharged at night when energy demand is low, run its regular schedule, and then discharge energy back into the grid when stationary. The technology also makes it possible to combine batteries from multiple vehicles into a virtual power plant. This combined energy can then be sold on energy markets or used to provide so-called network services during peak hours which help to stabilize the network and prevent breakdowns. V2G also saves fleet owners' money by charging them when electricity rates are low and can even power the building with cheap energy stored in EV batteries. All of this is done with priority on battery condition and making sure the vehicle is charged enough for daily driving tasks. According to one of the researchers, V2G can generate income and reduce the TCO of an electric vehicle by using batteries when the vehicle is parked and not driven [25]. Accelerating the development of the electric vehicle market and helping to integrate renewable energy into the electricity grid in Turkey.

Currently, there are several reasons why the demand side might be interested in electric vehicles and the concept of V2G. Due to COVID-19 and armed conflicts much attention to self-sufficiency and energy stability has been paid, and the purchase of an EV/BEV is an investment in local renewable energy infrastructure and reducing its dependence on imported oil. Researchers indicate 3 main reasons why electric vehicles are preferred in Turkey [26–28]. The first is energy security independence [26]: electric vehicles ensure energy independence and energy security. The second is the reduced environmental impact [27]: electricity used by electric vehicles is expected to come from existing PV installations currently used for other purposes. The third is the dynamic development of infrastructure for charging electric vehicles [28]. Advanced legislative works are underway on the act guaranteeing the development and availability of infrastructure. This work is coupled with plans to market the first Turkish electric vehicle. Togg electric cars [29] will be sold for the first time in Turkey from 2023.

Therefore, this article has many important practical implications, both political and economic. The scientific aim of the study is to analyze an optimal aggregator planning strategy for bidirectional V2G and create a coalition with renewable energy producers. This study extends the research conducted so far in the field of considerations concerning electric vehicles and vehicle-grid interaction in the Turkish power system. To the best of our knowledge, this article is the first in which the issues of electromobility and the stability of energy systems, and energy independence were combined, and the first case study was discussed regarding the domestic market. The key contribution of this study is to formulate optimal aggregator scheduling strategies for bidirectional V2G and minimize energy prices in the context of EV charging. Consequently, it significantly reduces the negative impacts of performing V2G on a distribution system. This method has been enriched with additional factors, ignored by many experts, concerning the amount of energy when charging and discharging as a result of the decrease in battery life depending on time which may affect the achievement of the desired synergy effect in the scope of the discussed issues

Briefly, this article brings new insights to the existing literature in the following areas: (I) Electric vehicles in Turkey (II) vehicle–grid interaction, (III) power systems, and Smart Grid (IV) energy independence. Contrary to other studies on this research topic, the presented research was carried out on a specific group with a 14-day period defined based on individual vehicle charging profiles in a 24 h cycle, taking into account the aggregator role of V2G in this process in relation to a specific destination city using a stochastic solver based on Matlab, not the linear or deterministic methods as before.

The article is organized as follows. Chapter 2 describes the problems and impacts of charging electric vehicles, and the advantages and disadvantages of V2G. Chapter 3 proposes a load model for electric vehicles and an algorithm for charging regulation is developed for EVs can perform the most profitable service. Chapter 4 discusses V2G with renewable energy and microgrid options and the results of simulation experiments are discussed. Chapter 5 presents the final conclusions of the research, indicating their limitations, practical application, and future directions of research in this field.

2. Problems with Charging Electric Vehicles in Turkey Advantages and Disadvantages of V2G

The Turkish government has set itself ambitious goals to put 2.5 million plug-in cars on the country's roads by 2030, but the number of electric cars in Turkey has reached 6333, of which 1764 were sold in the first 5 months of 2022 [30]. Although 1 million will probably not be reached by 2023, there is a very good chance that several hundred thousand of them will be in motion. It is worth noting that most of the cars sold so far have been Renault

Zoe type and plug-in vehicles and not purely electric [31]. In the case of high-power consumption, there may be problems with charging electric vehicles.

An electric car has the potential to double the energy load as long as it is only charged at home [32]. Should be noted that the current energy system in Turkey was not designed to service such a heavy load. Moreover, for many EV/BEVs, significantly worse results may occur in the distribution system than in the transmission system. Because many people are considering the purchase of electric vehicles, and all users will use the same public charging station so it is natural that local overloads and voltage problems can occur in the power grid. Moreover, the question remains whether the current energy potential from renewable energy sources will fully meet the market needs related to the growing energy demand in Turkey (Figure 1).

Figure 1. Regulation of the balance of energy production and consumption.

One of the tools that can help in solving this problem is technology (V2G), i.e., a vehicle-to-car interface that enables two-way communication with the electrical network. This means more or less that the electricity can not only be taken from the socket, but also transferred to it. Of course, communication is controlled by a special driver, and it is up to the driver to decide when the charging will take place. Thus, the car can be charged whenever the load on the electric network is lower, or when the night tariff becomes applicable, for example. In other words, the car then acts as an energy store that can be transferred to the grid when the need arises. This pattern of behavior allows not only to change the fee rates, but also to provide valuable services to the grid and participate in energy markets through an entity called an aggregator. By receiving vehicle locations from the internet or potentially from a wireless provider, the aggregator receives an offer from a large number of electric cars. The aggregator then contracts through the grid operator and provides services through the energy markets and controls the toll for the car, and collects the toll. Part of the fee is returned to electric vehicle users. In this way, customers can be incentivized to sign up for the system to be able to charge on that system where there will be no higher peak loads. Such a solution may bring you closer to the desired synergy effect.

In fact, additional electricity storage would be free of charge in this system to help address some of the major challenges of a multi-variable renewable electricity grid. This will make it easy to keep the system in balance. Although the citizens buy cars to get around it, in fact, most of the day vehicles spend their time in the parking lot. Thus, the house can be powered by a fully charged electric car battery for several days. If all Turkish vehicles were electric (25.5 million EV batteries), the total storage space would be huge. It is about seven times larger than the Karakaya Hydropower Plant (1800 MW), which completed construction in 1987. In addition, it is over 12,000 times larger than the large Hornsdale Tesla battery in Australia [33].

In the available literature, researchers emphasize that intelligent charging is a select group function that manages the charging power of electric vehicles in order to provide a cheap, sustainable, efficient, and flexible environment for the development of electric vehicles for charging [34]. Other researchers postulate that Smart Charging offers many benefits and opportunities in the future [35,36]. For example, it can improve charging flexibility by managing the charging power, charging power flow direction, and charging time. Due to the high flexibility of charging, fixed assets such as transformers and power grids can be used more efficiently, reducing the cost of charging EVs. Smart charging can help reduce energy consumption in the distribution grid by increasing the efficiency of energy transmission. Electric vehicles can also be made more environmentally friendly by recharging them using renewable energy sources. In addition, smart charging can provide EV owners with additional revenue streams, such as frequency regulation and vehicle-to-grid services. It should also be emphasized that the mentioned solution may contribute to reducing the problem with the disposal of used car batteries. After the traction battery is no longer able to store energy for a sufficient range, it can be removed from the vehicle, but the amount of electricity it can still store can be used in various ways, for example, a power bank. Thus, batteries will go through their entire life cycle, and then in a "closed loop" they will be recycled, from which raw materials will be extracted and reused to produce new battery components. As shown in Figure 2, with the maximum power for charging cars limited, Smart Charging can prioritize multiple charging locations or change the power of each charging station to stay within the maximum limit. Each EV can be charged with smart charging by different methods depending on priority and load. Smart charging can help regulate the charging power of an electric vehicle powered by intermittent renewable energy sources. Figure 2 shows the general system of the coordinated charging process for electric vehicles [35,36].

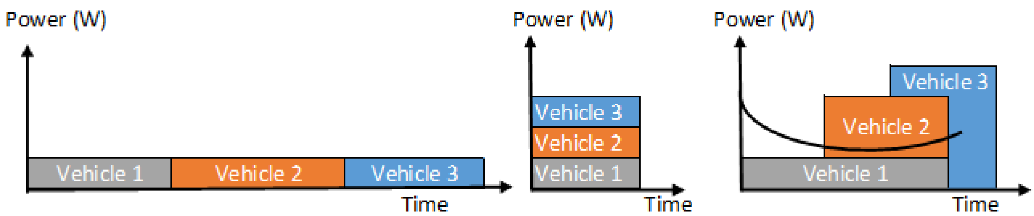

Figure 2. Approach to load balancing during loading.

V2G Advantages and Disadvantages

The most significant advantage is the fact that V2G allows energy to be stored in vehicles, especially from renewable sources, which results in their zero emissions. Additionally, by using the stored energy, you can reduce the peak demand of the electricity grid. In addition, electric vehicles can now be used as a critical component of an emergency power system. Finally, an EV with a V2G system can provide ancillary services to the network, providing income to the EV owner. At the same time, a number of serious problems with V2G are discovered. Two-way chargers, which are larger and more expensive than one-way chargers, are required for the V2G system to function. As bidirectional charging requires more charging cycles, the battery life of an electric vehicle is partially shortened and causes additional degradation. For example, one of the leading manufacturers of electric vehicles in Germany has limited the bi-directional operation of its models to 4000 h or 10,000 kilowatt hours. After this time has elapsed or this amount of energy has been used, the bidirectional charging function will be turned off. The restriction was probably imposed in order not to contribute to the accelerated degradation of the cells. In the case of the cells with nickel-manganese-cobalt (NMC) cathodes used by the manufacturer, 800–1000 full cycles of operation, ranging from 0 to 100 percent, are considered a standard. Discharging and recharging between 80-20-80 percent is theoretically 0.6 of a full cycle, but current experience suggests that narrower intervals cause less degradation than suggested by this calculation. In addition, the ICT infrastructure, the required standardization and regulatory framework, and the financial incentives needed to implement V2G are still under development in Turkey. Finally, it should be noted that it is currently not possible to connect a vehicle to the grid using AC chargers due to technological limitations. This is because a two-way on-board charger is needed to connect the vehicle to the grid, but most current electric vehicles only have one-way chargers that are on board. Moreover, V2G requires higher levels of communication between the charger and EV, which is not satisfied by simple communication with pulse width modulation in AC type 1 and type 2 chargers. Hence, bidirectional external DC chargers are used for V2G applications using a higher level of communication, through network communication, control area, or network communication [37–39]. The advantages and disadvantages of V2G are summarized in Table 1. The V2G concept has been described in detail in the literature [39–41]. The V2G system is an important aspect of a smart grid, along with an industrial area [42], a residential area [38], and a construction area [43].

Table 1. Advantages and disadvantages of V2G.

Currently Restrictions	Benefits
No bidirectional chargers in vehicles. V2G needs bidirectional chargers which are more costly and bigger than unidirectional charges.	Storage of renewable energy
Battery degradation	Peak demand reduction
No ICT infrastructure	Emergency power supply
Lack of standardization and regulatory framework	Additional services
No incentives for the user	Grid operators can stabilize the grid and optimize investments

At this stage of consideration, it should be emphasized that with the increase in the number of electric vehicles creating a real chance for grid balancing, scientists and researchers are working on optimizing design parameters, which can provide profit for both EV users and grid operators. Over the past decades, various types of V2G system configurations have been developed [44,45], and productivity and profitability have been maximized. For example, the project [46], which shows how V2G works on a large scale, includes 51 electric vehicles that are part of the Australian Capital Territory government fleet. It works so that the batteries in electric vehicles are connected to the grid via a two-way charger. They monitor the grid frequency to see if there is a balance between electricity supply and demand. When the demand becomes higher than the supply, the frequency decreases and the EV batteries reconnect to the grid. When the supply is higher than the demand, the frequency increases, and the EV batteries begin to charge to take over some of this extra load. Another project [47] in the UK is called 'Vehicle to Grid Oxford'. The project aims to develop a legal framework that can then be easily replicated in parking lots. They look at fleets of electric vehicles, and therefore mainly suppliers. One of the main results is examining the business models behind V2G as there are technical operations and the question is whether they can align the technical capabilities with the markets and business models of the people involved. It was calculated that part of the project was that if all the cars on the road were electric and were able to offer V2G, it could power the entire UK for two days using the energy from those cars' batteries!

In summary, there are many other reports and projects [48–50] on V2G modeling, grid design, analysis [51], and renewable energy integration [52]. However, most studies used linear and deterministic methods. In contrast, in the study presented below, a Matlab-based stochastic solver is used.

3. Materials and Methods

3.1. Conceptual Assumptions

Figure 3 shows the hourly load curve for the city of Istanbul derived from the [53]. The energy market would be an economic shipment where generators schedule hourly blocks of energy to run at a certain level for an hour. In the next shipment period, another generator is agitated and runs at its peak for an entire hour to cope with this load. There must always be an ideal generation load balance in the power system, otherwise there will be a failure. This is the high-frequency component and is satisfied by generators that respond to fluctuations every 4 to 10 s, and this is called regulation. Up-regulation, which means generation increase, and down-regulation to reduce production. There is also a gradual increase in the burden that is provided by market balancing. To cope with sudden load shedding, there should be contingency reserves that should emerge where other generators emerge, i.e., a sensitive reserve market should be created.

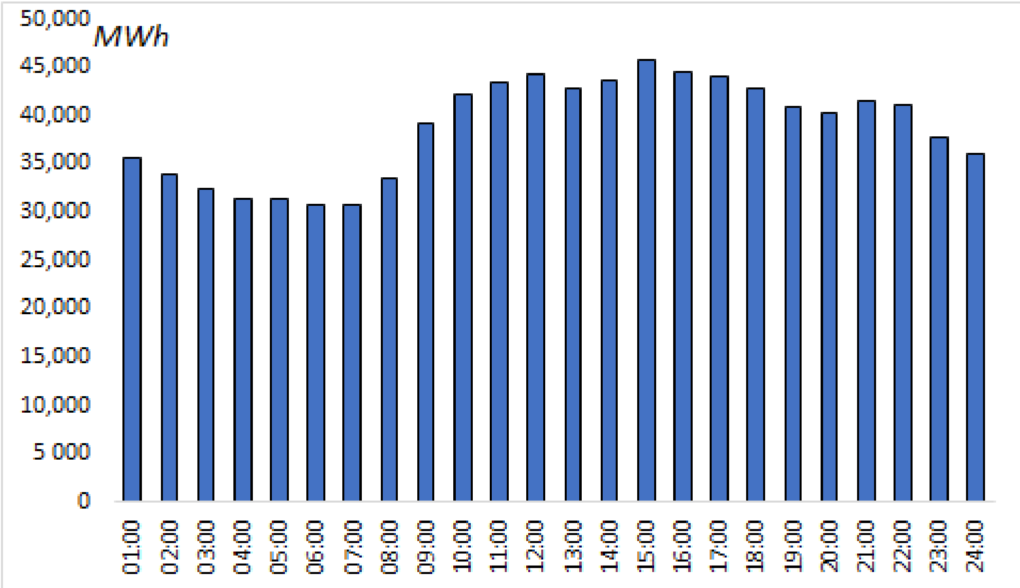

Figure 3. Hourly load for Istanbul (31 May 2022).

Electric vehicles can participate in these markets without draining the battery. The unidirectional operation of the V2G is that electric vehicles set an average charge speed called the duty point, and then can increase and decrease their charge. As the increasing generation is analogous to decreasing the load. It is also possible to perform by increasing the load. Each electric vehicle owner has to adjust the charging rate to participate in these markets and does not have to discharge the battery to the grid, which makes many happier because owners of electric vehicles do not want the grid to discharge their load and remain immobilized.

3.2. Optimal V2G Planning

The aggregator can be a third party or a company that contracts the electric car charging block and sells energy in the markets to make a profit [54]. The aggregator's goal is to maximize profit through the combined optimization of V2G services. Like many distribution companies, the aggregator's profit comes from a percentage of V2G services in the market, distributes the rest to customers, and pays a margin on the wholesale energy price. The cost of the aggregator for planning purposes is fixed as it communicates the energy price to the customer in real-time. There are other revenues that an aggregator may have, such as responsive energy reserves, or down regulation and up regulation. Optimal sale and purchase of energy in V2G is discussed in [55]. None of the studies looked at aggregator strategies and income structures, or V2G ancillary services. In contrast, the study [56] included regulations, V2G benefits and contingency provisions, but did not take into account the share of aggregators.

EV charging has a number of negative effects on the distribution system, including poor voltage profiles, higher losses, and feeder overloads. Coordinated charging with the aim of reducing losses is one technique to mitigate them. The objective function of this study, V2G scheduling in electricity markets is optimized to provide maximum benefits to the system and the customers.

3.3. V2G Optimization Limitations

Charger limits: set according to the maximum charging speed of the charging station or the maximum charging speed of the internal charger. For example, if users connect their car; most chargers can only handle around 6 kW. However, e.g., a Nissan Leaf with an on-board car charger can operate only with a power of 3.3 kW [57].

$$(PD_{max,t} + BEP)EV_{cf,t}\, Ef_t + SOC_{i.t} \leq CH_{max}, Av(t) \tag{1}$$

Battery capacity limits: the vehicle owner may not be able to charge the battery to 100%; often these limits are set by the battery manufacturers. Tesla vehicles usually set this to around 90% to protect it to extend battery life. Batteries drain faster when they are 100% charged.

$$\sum_{t=1}^{km} \Big(E(Pw_t(t))EV_{cf.t}(t) \Big) Ef_t + SOC_{i.t} \leq CH_{max} \tag{2}$$

EV Availability: uses the expected values of the available EVs. Projected transport profiles with associated probabilities. Electric vehicles can unexpectedly leave and the V2G contribution has to be compensated by other EVs.

$$BEP(t) \geq 0 \tag{3}$$

Value-added limitations: aggregators cannot sell negative values of different yields. Upregulation and reactive power reserve must not be greater than the Best Efficiency Point (BEP) [58].

$$PD_{max}(t) \geq 0 \tag{4}$$

$$PD_{min}(t) \geq 0 \tag{5}$$

$$PD_{rdc}(t) \geq 0 \tag{6}$$

Dispatcher's compensation for unexpected EV departures [58]:

$$EV_{ud,t}(t) = 1 + \frac{Dpr(t)}{1 - Dpr(t)} \tag{7}$$

3.4. Tool Description and Sampling Method

The optimal algorithms are simulated over a 14-day period on a hypothetical group of 2500 electric vehicles used by commuters in the Istanbul area. This system is simulated in Matlab using an optimization toolkit to solve optimization. Each simulation day starts at 8:00 am and ends at 8:00 am the next day. Each battery SOC from the previous day is assigned as the starting SOC for the new day. In this study, the system, the load, and market prices of electricity for electricity are derived from the available TEIAS YBTS [53] archives for the period 1 to 14 May 2022.

A daily driving profile for each electric vehicle allocated in Istanbul was randomly assigned. Each daily driving profile includes its own morning and evening start times, commuting times, and commuting lengths. The hours of commuting to work in the morning ranged from 6.00 a.m. to 9.00 a.m., while the evening commuting hours ranged from 4.00 p.m. to 7.00 p.m. The starting time of the first trip ranged from 11:00 a.m. to 2:00 p.m., while the starting times for the second trip ranged from 5:00 p.m. to 8:00 p.m. Additionally, there is an unexpected possibility of departure every hour that an electric vehicle is available to carry out V2G. A 10% probability of leaving work early and an additional 20% of an evening trip home are added to the calculation. All electric cars are assumed to be parked and unused from 03:00 a.m to 6:00 a.m.

The aggregator's income comes from two sources, cooperating with renewable energy producers, the aggregator buys electricity from the producer cheaply and sells it at a higher price; the *Cpr* and a fixed percentage of the ancillary services revenues *k*. In this study, it is assumed that $0.81/kWh is the market price of energy supplied to cars and the aggregator receives 15% of the ancillary service revenues. For the net energy consumed each hour, the aggregator pays the wholesale energy price.

$$maxP$$

$$P = income - cost \tag{8}$$

$$income = \%k\sum_{t}\left(\left(R_D\sum_{t}\vec{EVcars} + R_U\sum_{t}\vec{EVcars} + R_R\sum_{t}\vec{EVcars}\right)PEV(t)\right) + \left(Cpr\sum_{i}\sum_{t}PD_i(t).PEV(t)\right) \tag{9}$$

$$cost = \sum_{i}\sum_{t}Pw_t(t).Elpr(t) \tag{10}$$

3.5. Charging Profiles

The auxiliary capacities and charging profiles for 3 May are compared, taking into account the coalition with renewable energy producers. This day was chosen because the fluctuations in hourly electricity prices better emphasize the divergent behavior of the algorithms. Electricity prices per hour are shown in Figure 4. The price range is USD 24 per megawatt to USD 37 per megawatt.

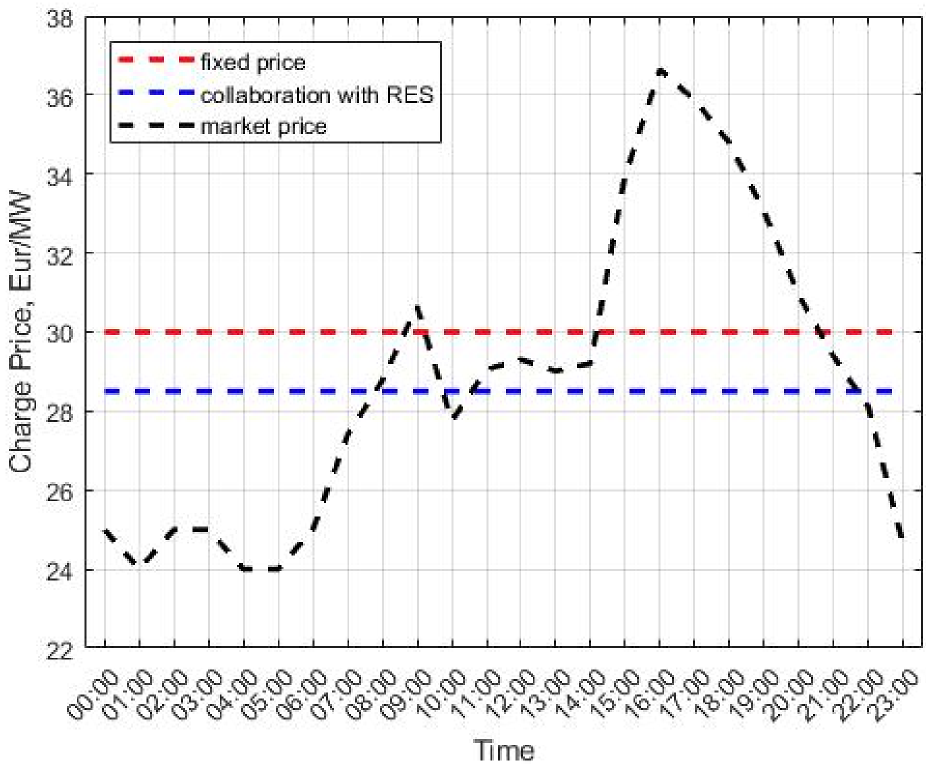

Figure 4. Prices for hourly billing services as of 2 May 2022.

The aggregator receives 15% of ancillary service revenues and 0.02 USD/kWh over the spot market price. Includes 24 h electric vehicle charging planning based on the most likely driving profiles. Istanbul is assumed to have a hypothetical fleet of 2500 different electric cars, these were the BMW iX3, the plug-in Renault Zoe, and the Mini Cooper SE. It is also assumed that the aggregator cooperates with a company producing renewable energy and receives electricity directly from the producer. Shapley Value is used for an equitable distribution of income [59].

Optimization cells reduce regulation, and this is where the type of maximum income comes into play. The aggregator sells services at really high peak prices, and that is when the interesting mess begins when half of the cars leave work and go home. Thus, charging stations have limited availability after 4 p.m., and the number of sales is growing. Optimal behavior is what is expected given the different conditions of everything. Charging service capabilities and charging profiles for optimization algorithms are shown in Figure 5. It can be seen that the price-based energy consumption in Figure 5 always takes into account lower prices and higher capacity.

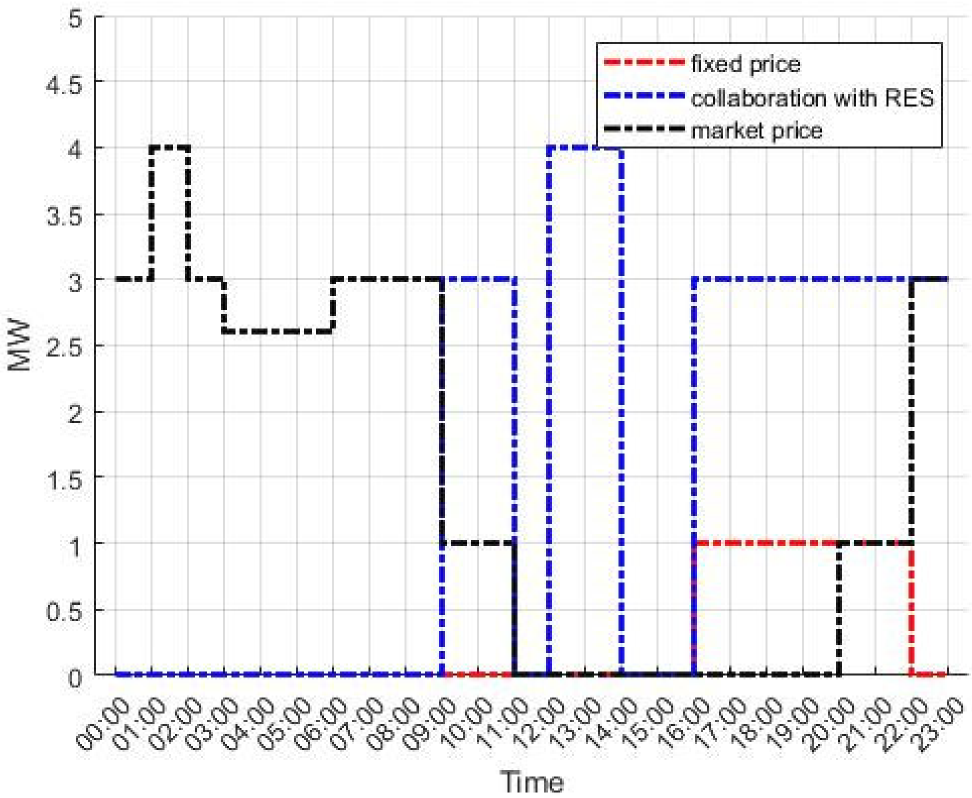

Figure 5. Hourly optimized charging profiles.

3.6. Findings on V2G Optimization

The hourly charging profiles are shown in Figure 5 and the test results for a total of 2500 cars are summarized in Table 2. An aggregator can earn approximately USD 14,660 during these 14 days and provides an average of 3 MWh of hourly charging capacity. Customers are done with payments and pay less than 0.081 USD per kWh for fairly cheap electricity. It can therefore be seen that V2G can provide significant regulatory and fallback capacities. It can provide valuable income for aggregators and customers. V2G can provide significant reserves of power and regulation. V2G generates valuable revenue for both aggregators and customers.

Table 2. Results of the study.

Average Hourly Charging Capacity	**3 MW**
Average peak load increase	1.5 MW
Maximum peak load Increase	10.9 MW
Electricity price for the customer	USD 0.081/kWh
Aggregator Profits	USD 14,660

However, most problems would arise in the distribution system, which has not been addressed but can be accommodated through feeder-specific load constraints. Because this operation should not harm the distribution system. This load limitation can then be designed to be integrated into an optimal V2G formula. Keeps the load below a certain desired level while executing the V2G service.

$$\max_{t}\left(L_{id,\ k}(t)+\sum_{feeder\ min}^{feeder\ max} PD_{max,t}(t)+BEP_t(t)\right)\leq I_{id.\ k}(max) \quad (11)$$

where $I_{id,k}(t)$ is feeder load k without EVs in time t.

The feeder load limitation is shown in Equation (11), where the sum of the aggregate has the maximum feeder base load, and all electric vehicles on this feeder have growth potential. It keeps it below the maximum value it used to be, as otherwise it could have unwanted effects on the distribution system. It is divided into the same type of electric car group. Supply voltage losses and line overloads are compared to see the states of both algorithms. The EV loads are distributed over all small EV points, as shown in Figure 6.

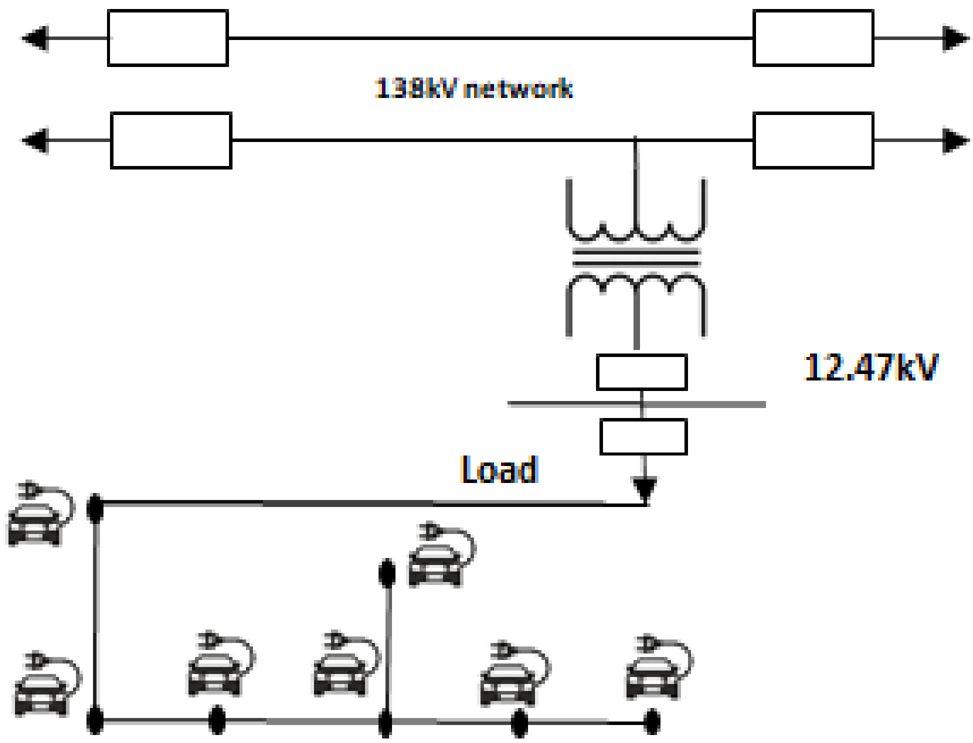

Figure 6. The seven-wire distribution system used in the simulation.

The results in Table 3 show that losses increase when electric cars are added. When a feeder-specific constraint is applied, losses can be reduced by more than 3%. If the maximum line currents are reduced and the feed field limitation is not taken into account, an overload may occur during the two weeks when the feeder is overloaded. However, this can be avoided by placing a tray restriction on the system. According to ANSI standards, the minimum allowable node voltage must be 0.95 or more (max 1.05), and if it falls below this, problems may arise in the system [60]. The base case was above it, the opt feeder algorithm also held above it, though barely.

Table 3. Compare the optimized case of the study.

Loose line	Base	29.5 MWh
	Optimized	34.5 MWh (Revised losses 3.04%)
Maximum line currents	Base Optimized	32 A 40 A
Service voltages in p.u.	Base Optimized	0.954 0.957
Number of overloads	Base Optimized	0 0

4. Discussion

Where the greatest load is added to the mass electrical network by electric cars; without limitation it can be up to 1.59 MW, while the average is around 0.3 MW, while the maximum never exceeds 0.5 MW and the average is less than 0.2 MW in the optimized version (see Figure 7). From the point of view of the mass system, this limited optimization is much better for them but reduces the aggregator profit. Limiting the feeder load reduces losses, eliminates overloads, and eliminates voltage failures. It also reduces the price of energy people have to pay as it replaces most of the charge at night when it is not that expensive. Therefore, if it is known whether the aggregator is a third party to reduce the load on the power supply, it can eliminate overloads, and voltage drops can reduce losses.

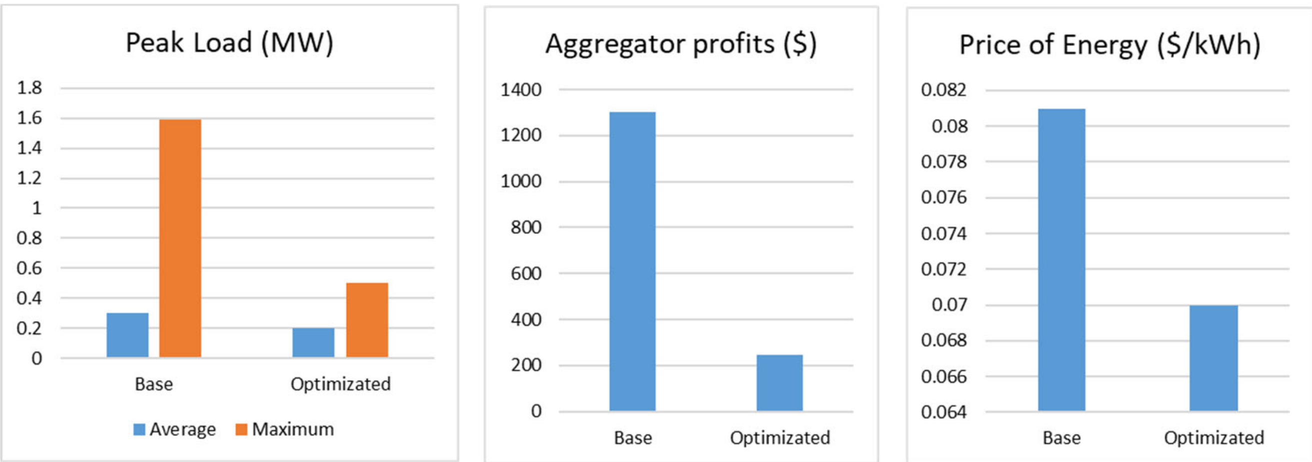

Figure 7. System and economic results of the study.

4.1. Bidirectional V2G

It works very much like a unidirectional V2G but allows it to be discharged from the battery to participate in the electricity market. However, battery degradation and minimal customer riding needs should be considered as commuters should have enough batteries to drive home. There are two major complications to trying to formulate an optimal schedule in this way. This is a round-trip abuse of capacity by the aggregator. The second is to formulate as a convex optimization problem due to the nature of battery degradation and the way of limiting the battery SOC.

4.2. Round-Trip Misuse

The aggregator obtains income from selling energy to electric vehicles and the market. The aggregator knows that the battery is not 100% functional and can discharge it to zero without paying the customer, then recharge it to refill it, and then discharge it again. For example, as seen in Figure 8, the customer buys 6 kWh with 90% battery efficiency.

The customer receives 5.4 kWh in the battery; the price of energy does not change. The aggregator discharged the battery which is 6 kWh. Therefore, the customer consumes 6.6 kWh with 90% efficiency of the battery. The generator pays the customer for 5.4 kWh who lost 1.2 kWh of energy from the battery.

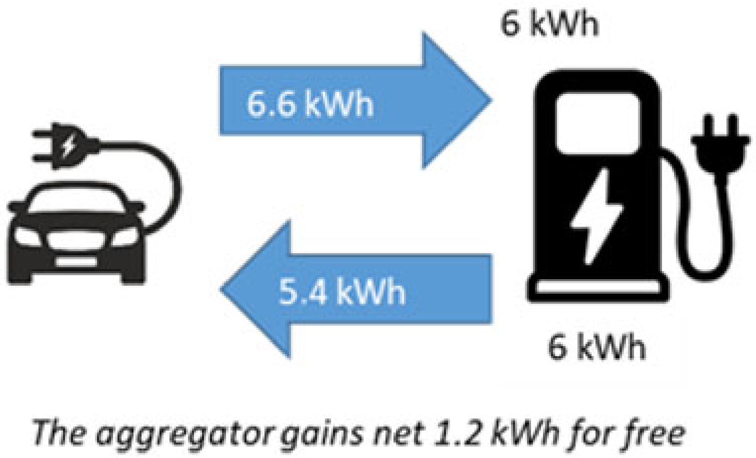

Figure 8. Abuse of efficiency in both directions.

This means that the aggregator is discharging something from the battery; essentially pays the customer for 1.2 kWh, or what the customer loses.

4.3. Battery Status of Charging Problem

The ability to charge or discharge in a given period depends on the condition of the battery in the previous period. However, it can be linearized by limiting the total sum of the expected power consumption of an electric vehicle in each period of time. Each charging period may be limited to the maximum to be less than the maximum and greater than the minimum. The next planning period should be included as part of the constraints.

4.4. Two-Way Results

Using the same simulation system; Figure 9 shows three different battery replacement costs, which is the biggest problem. Compared with the one-way profit, they are almost 10 times higher, and the effect of the system is better. From the aggregator's point of view, the cost of the batteries determines how much needs to be passed on to the customer to compensate for costs. From a systemic point of view, the system supports this as it is moderately discharged, so it becomes an asset, not a burden.

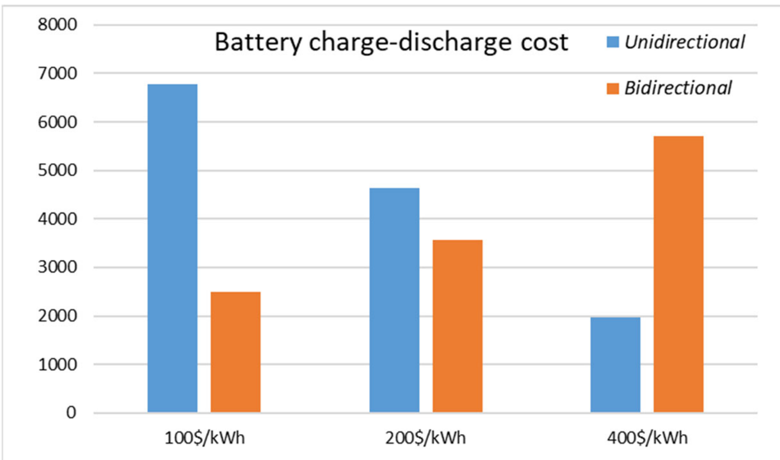

Figure 9. The cost of charging and discharging the battery.

4.5. Modeling of the EV Load

Earlier studies assumed that the EV charging power was constant depending on the system conditions. Unfortunately, all these models do not take into account how the EV itself will behave after a system change. It will change the voltage as the power flow changes, so it is imperative to study how the EV loads change with the system voltage. The battery voltage level graph is shown in Figure 10 with five different Nissan Leaf, Tesla S, Hyundai, Ford, and Mercedes cars connected to a power source. It shows that the cars behave extremely differently, from 59 to 205 V. Especially the Ford and Hyundai which intend to behave similarly but do not after a while and have three different tiers; additionally, the Mercedes beats them when it gets to the top. The Model S and Nissan are linear, but not on the same level. Each EV behaves differently in terms of voltage response. Therefore, the use of one general model may give inaccurate results in the studies.

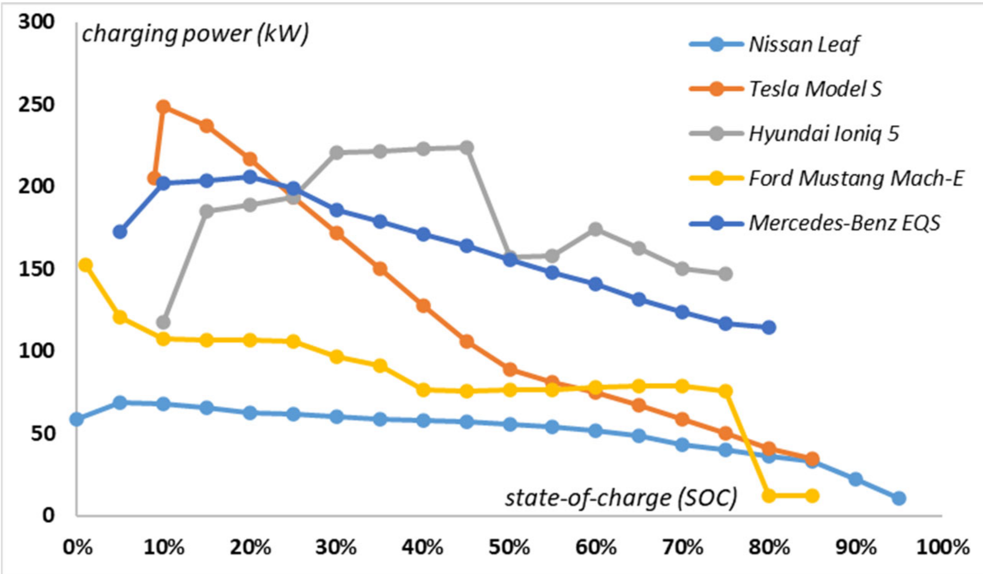

Figure 10. Instantaneous charging power and SOC.

5. Conclusions

The increase in electricity consumption, both industrial and individual, in recent years, including the constantly growing market for electric cars, means that Turkey's national power system is again facing the known problem of a lack of production and transmission capacity. The development of distributed energy, using local renewable energy sources, has been presented for a long time as one of the solutions increasing the stability of the grid and facilitating the balancing of supply and demand in the electricity market [61–63]. An example of this approach is numerous home photovoltaic installations, the market of which has been growing at an impressive pace since the introduction of financial support for investors. The concept of V2G seems to be not necessarily new, but still quite futuristic for most citizens. The literature on the subject emphasizes [4,64,65] that it is a concept that allows for bidirectional electricity transmission between an EV/BEV connected to a charging station and the power grid. In this way, the car owner becomes, similarly to the energy market, prosumer and a link in the distributed energy system.

On this basis, the authors support the thesis put forward by other researchers [66,67] that the V2G concept is part of a wider issue, which is the Smart Grid, which is one of the solutions increasing the security of the power system through its decentralization. Thanks to advanced charging control and V2G, electric vehicles can be safely integrated into the power system. V2G provides significant benefits and benefits to all interested parties. V2G also has many additional uses and smart grids, such as the integration of renewable energy and microgrids. Renewable energy sources, especially that wind and solar, have discontinuous and variable efficiency [68]. V2G has the ability to smooth out outputs and potentially store excess energy until needed. However, as researchers have shown, EV/BEV and V2G vehicles can overcome this problem. This solution can be used to integrate renewable energy systems. It is also possible to use V2G with microgrids. In particular, the microgrid is a small set of loads and generations in an energy distribution system that can be the backbone of the main power grid. V2G can provide massive energy storage and the necessary regulation to maintain the microgrid frequency in the event of voltage and frequency fluctuations, ensuring network reliability and security. Therefore, it is very valuable for the stability and control of small power systems.

An important postulate in these considerations in relation to the vehicle-energy network interaction is also to emphasize that Vehicle to Grid is also a way to increase the energy independence of a household. In the case of charging the batteries in the vehicle with clean, green energy from a private, home solar power plant, the negative impact of the EV/BEV on the natural environment becomes negligible. In addition, the "mobile warehouse" is supplemented directly with free energy obtained from renewable sources, in particular, we are talking about highly sunny areas. In this way, the peak energy demand within the house will be satisfied from the surplus production of the PV plant accumulated in the battery unit, thus avoiding buying energy from the operator. Such a solution can also be an emergency source of energy in the event of unforeseen blackouts occurring in the network. Harvesting energy can provide a cost-effective alternative to costly R&D investments as it supports peak performance where it is needed most. At the same time, they indicate the achievement of the currently desired and difficult-to-implement synergy effect [69].

Research has shown that the unidirectional V2G designs can be expanded to bidirectional V2G. The findings indicate that, for different battery charge/discharge costs, the profits are notably higher than unidirectional V2G. Electric energy prices are also significantly lower. Although there are challenges in implementing bidirectional V2G, it is clear that it can be overcome and profited. Simulations on the Turkish system show that aggregators can potentially receive USD 247 with keeping EV owners' costs 0.07 USD/kWh. At the same time, the aggregator offer is not optimal for owners of electric vehicles. If electric vehicle owners implement similar strategies, charging costs are reduced by close to 60%, as they do not have to pay the aggregator for the service.

This is the first study to analyze the impact of electric vehicles and their vehicle-grid interaction in the Turkish electricity system. This type of research has its limitations. From a scientific point of view, it should be emphasized that the potential benefits of V2G reserves, such as the lowest price for customers through a coalition with renewable energy producers and financial incentives for early adopters of electric vehicles are significant, and also a strong business case for aggregators due to the income potential that aggregators can generate. Certainly, in the near future, much more extensive analyzes and research will be needed, in particular with regard to the idea of an aggregator institution understood as an entity dealing with aggregation, but also an independent aggregator, i.e., an aggregator that is not related to the recipient's seller and with which a service contract has been concluded aggregation. In addition, further research on this topic should focus on the technical aspects related to the degradation process of the traction battery as a result of its use as energy storage. Another important research area that will appear in the development of the idea discussed in the article is connecting millions of low-power sources to the currently functioning energy system and the issue of its possible destabilization due to the transmission of high power from electric vehicle batteries to the system.

Summarizing the analyzes presented by the authors concerning electric vehicles and their interactions in the vehicle-grid system in the Turkish power system, do not fully exhaust the essence of the issue, but are only an attempt to signal the complexity of the analyzed issues. Concerning interconnections related to the development of electromobility, energy demand, and energy security. These issues will certainly be the subject of further analyzes and research in order to assess the legitimacy of implementing solutions based on the idea of electromobility in relation to road transport in countries such as Turkey.

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Abbreviations

HEV	Hybrid electric vehicles.
PHEV	Plug-in hybrid electric vehicle.
BEV	Battery electric vehicle.
FCEV	Fuel cell electric vehicles.
ICE	Internal combustion engine.
PD_{max}	Maximum power consumption EV.
PD_{min}	Minimum power consumption EV.
PD_{rdc}	Power consumption reduction EV.
BEP	Best performance point.
EV_{ud}	Unexpected departures compensation coefficient.
SOC_i	Initial state of charge.
SOC	State of charge.
CH_{max}	Maximum battery charging capacity.
Av EV	availability.
Pw_t	Total power consumption.
Ef	Efficiency of the battery charger.
P	Profit.
k	Percentage of revenues earned by the aggregator.
t	time index.
i	electric vehicle index.
R_D	electric energy of the regulation reduced for the time t.
R_U	electric energy regulation until time t.
R_R	electricity reserved for the period t.
EVP	Expected percentage of electric vehicles not performing V2G.
Cpr	Electricity price for V2G aggregator customer.
PD	Final power consumption EV.
Dpr	Probability of unexpected EV departure.
$Elpr$	Electricity price, which can be a fixed, market or coalition price.

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