User-Comfort Oriented Optimal Bidding Strategy of an Electric Vehicle Aggregator in Day-Ahead and Reserve Markets

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Abstract

With the increase in the number of electric vehicles (EVs), there might be substantial problems due to the charging transactions in the power system and the balancing between supply and demand sides can be provided in the modern power system by considering EVs as a flexible load. EVs cannot directly participate in buying and selling energy from/to the electricity market because of their relatively low energy and power capacities. In this manner, considering that EVs are generally parked during the day, an EV parking lot (EVPL) can offer economic charging opportunities to EV owners as multiple EVPLs can offer/bid for the buying/selling from/to the electricity market through an EVPL aggregator (EVPLA). In this study, a model in which the EVPLA offers/bids for the day-ahead (DA) and secondary reserve market in order to minimize the total cost is propounded. Furthermore, uncertainties related to the EV owners' behavior and market prices are handled by considering scenarios with real data in a stochastic manner. In addition, the EVPLA also takes into account the comfort of the EV owners when carrying out this operation. The comfort of EV owners as an essential issue similar to serving EV owners more economically is achieved by sustaining the minimum desired charge level by EV owners at the departure time. The results consist of a set of case studies to reveal the effectiveness of the proposed model considering the pricing conditions in Turkey, Finland, and USA-PJM DA and reserve markets. According to the results of the study, it is observed that an EV aggregator participating in DA and RE markets can make a significant profit for the three market conditions. An important result is also that the profit by the participation in reserve markets increases significantly compared to solely DA market participation.

Keywords: Electric vehicle; electric vehicle aggregator; electric vehicle parking lot; electricity market; optimal bidding.
Nomenclature

**Abbreviations**

DA  
Day-ahead

EV  
Electric vehicle

EVPL  
Electric vehicle parking lot

EVPLA  
Electric vehicle parking lot aggregator

PL  
Parking lot

SoE  
State-of-energy

**Sets and Indices**

\( p \)  
Set of EVPLs.

\( h \)  
Period of the day index in time units [hour].

\( v \)  
Set of EVs.

\( s \)  
Set of scenarios for EV behaviors.

\( t \)  
Period of the day index in time units [5 min].

\( w \)  
Set of scenarios for market prices.

\( \Delta_t \)  
Set of sub-time intervals \( t \) within one hour.

**Parameters**

\( CE_{p,v}^{EV} \)  
Charging efficiency of EV \( v \) in EVPL \( p \).

\( DE_{p,v}^{EV} \)  
Discharging efficiency of EV \( v \) in EVPL \( p \).

\( CR_{p,v}^{EV} \)  
Charging rate of EV \( v \) in EVPL \( p \) [kW].

\( DR_{p,v}^{EV} \)  
Discharging rate of EV \( v \) in EVPL \( p \) [kW].

\( f_s \)  
Probability value of scenario \( s \) for EV behaviors.

\( g \)  
Weight to adjust the comfort level of the EVs [0-1].

\( h_{st} \)  
Starting hour of the bidding to DA and reserve market.

\( h_{end} \)  
Ending hour of the bidding to DA and reserve market.

\( k_w \)  
Probability value of scenario \( w \) for DA and reserve market prices.

\( p_{w,h}^{DA,buy} \)  
DA market prices in scenario \( w \) during hour \( h \) [EUR].

\( p_{w,h}^{Res,cons} \)  
Reserve market prices in scenario \( w \) during hour \( h \) [EUR].

\( SoE_{p,v}^{EV,ini} \)  
Initial SoE of EV \( v \) in EVPL \( p \) [kWh].

\( SoE_{p,v}^{EV,max} \)  
Maximum SoE of EV \( v \) in EVPL \( p \) [kWh].
$S_{\text{EV,min}}^{p,v}$ Minimum SoE of EV $v$ in EVPL $p$ [kWh].

$t_{a}^{p,v,s}$ Arrival time of EV $v$ in EVPL $p$ for scenario $s$.

$t_{d}^{p,v,s}$ Departure time of EV $v$ in EVPL $p$ for scenario $s$.

$TR_{x,a}^{EV,\text{ch}}$ Total maximum charging energy of EVs in EVPLs within scenario $s$ during hour $h$ [kWh].

$TR_{x,a}^{EV,\text{disch}}$ Total maximum discharging energy of EVs in EVPLs within scenario $s$ during hour $h$ [kWh].

$\Delta T$ Time granularity.

$t_{st}$ Starting period of the bidding to DA and reserve market.

$t_{end}$ Ending period of the bidding to DA and reserve market.

**Variables**

$c_{\text{DA}}^{buy}$ Cost of buying energy from DA market [EUR].

$e_{x,h}^{DA,\text{buy}}$ Energy purchased from DA market in scenario $s$ during hour $h$ [kWh].

$e_{x,h}^{DA,\text{sell}}$ Energy sold to DA market in scenario $s$ during hour $h$ [kWh].

$e_{x,t}^{\text{EVs,buying}}$ Total energy charged to EVs in scenario $s$ during period $t$ [kWh].

$e_{p,v,s,t}^{EV,\text{ch}}$ Energy charged to EV $v$ in EVPL $p$ during period $t$ in scenario $s$ [kWh].

$e_{x,h}^{EVs,\text{consum}}$ Total energy charged to EVs in scenario $s$ during hour $h$ [kWh].

$e_{x,h}^{EV,\text{disch}}$ Energy discharged from EV $v$ in EVPL $p$ during period $t$ in scenario $s$ [kWh].

$e_{x,h}^{EVs,\text{selling}}$ Total energy discharged from EVs in scenario $s$ during hour $h$ [kWh].

$e_{x,h}^{Res,\text{consum}}$ Energy offered to the reserve market as consumer in scenario $s$ during hour $h$ [kWh].

$e_{x,h}^{Res,\text{prod}}$ Energy supplied to the reserve market as producer in scenario $s$ during hour $h$ [kWh].

$i_{Res}\,_{\text{consum}}$ Income obtained as consumer from reserve market [EUR].

$i_{Res}\,_{\text{prod}}$ Income obtained as producer from reserve market [EUR].

$i_{DA}^{sell}$ Income of selling energy to DA market [EUR].

$p_{x,s,t}^{EV,\text{ch}}$ Charging power of EV $v$ in EVPL $p$ during period $t$ in scenario $s$ [kW].

$p_{x,s,t}^{EV,\text{disch}}$ Discharging power of EV $v$ in EVPL $p$ during period $t$ in scenario $s$ [kW].

$SoE_{p,v,s,t}^{EV}$ SoE of EV $v$ in EVPL $p$ during period $t$ in scenario $s$ [kWh].

$u_{p,v,s,t}^{EV}$ Binary decision variable for charging and discharging of EV $v$ in EVPL $p$ during period $t$ in scenario $s$. If 1, it is charging, else 0.
1. Introduction

1.1. Motivation and Background

Regarding the dual reasons of limited fossil fuel resources and the adverse environmental problems caused by the widespread use of them, there is an intense interest in the use of electric vehicles (EVs) [1]. The global EV market has grown significantly in the world in recent years, e.g. the total number of EVs on road increased by 2 million more than the previous year and exceeded 5.1 million in 2018 [2]. With the increase in the number of EVs, the load profile in the power grid will change, and this possibly uncoordinated and random large-scale load will cause some challenges in the grid operation [3]. Voltage fluctuations may occur in the power system, and it may result in reduced system efficiency. Besides, this situation may reduce the lifetime of the transformers due to additional stress, and it may even cause a power failure due to overloading the system [4], [5]. Apart from all these negativities in terms of the grid, EVs can on the other hand be considered as a flexible load and can provide an essential opportunity for the management of demand-side and the functioning of energy markets [6].

Considerable time is required for charging of EVs as it may take several hours to charge a moderate battery. EV parking lots (EVPLs) play an important role in eliminating this disadvantage, considering that EVs usually stay in the EVPL for a long time, and increasing the prevalence of the use of them [7]. The EVPLs are similar to traditional car parks, but also offer an opportunity to charge EVs in where the EVs can be considered as including both grid-to-vehicle (G2V) and vehicle-to-grid (V2G) operational possibilities [8]. While the use of EVs as distributed resource/load, energy storage or generation device within the grid is defined as V2G [9], the G2V mode is considered as consumer mode where EV acts as a load [10]. EVs do not actually need to be charged as soon as they arrive or continuously during their stay in the EVPL in G2V mode where the charging program can be created for a specific purpose, and the process can be performed accordingly [11].

A single EV cannot meet the condition of energy market participation with its relatively small energy and power capacity. Therefore, to perform these operations, the EV parking lot aggregator (EVPLA) that is an alternative market participant is needed for the smooth operation of the transactions between the market operator, the EV owners, and the system operator [12]. The EVPLA is responsible for controlling EVs’ charging and acts as a medium between the EVs and the power system [13]. The EVPLA makes separate quantity-price pairs offers for buying and selling energy from/to the electricity markets, taking into account the behavior of the EVs in the EVPL. The aim is to buy energy at the lowest possible price and sell it at the highest possible price [12], and accordingly an EV owner can have the opportunity to charge the EV economically if the EV owner parks the EV in an EVPL. EVPLA can manage one EVPL as well as multiple EVPLs.
Bilateral agreements between the EVPL and the EV owner can determine several issues such as EV battery degradation, minimum charge rate at the departure time, charging tariffs, and the penalties if EVs do not comply with the agreement. The agreements generally are in a structure that EV owners are willing to participate voluntarily. EV owners want to make an agreement only if it is profitable. Since EVPLA charges the EVs most economically and makes a profit, it is quite possible for EV owners to make a profit through bilateral agreements. It should here be noted that bilateral agreements between the EV owner and the EVPL owner are not considered in this study due to the fact that the current study considers the problem only from EVPLA side, therefore the transactions between the EVPL and EV owners comprise another level of the greater scale of the problem that is not in the scope of the current study.

The EVPLA takes into account several situations when offering/bidding on energy markets. It has become an important issue that EVPLA determines the amount of offer/bid for economical operation and which markets it participates in as there is a great possibility of profit from appropriate market participation or vital reduction in profit and even loss from inappropriate market participation. The EVPLA can participate in day-ahead (DA), adjustment (known as the intraday market in Europe), reserve, regulation, and real-time balancing markets [14]. The offer-taking structure of each market takes place differently, and it is explained at different times before power delivery. For example, the DA market is announced immediately before the reserve market is announced. Market Operator clarifies the DA market offers, while independent System Operator clarifies reserve market offers. DA markets, where energy transactions are performed for the next day, are usually announced at noon the day before delivering power. The reserve markets provide backup power that will be activated when the system is in adverse operational conditions such as major outages, congestions, etc. The EVPLA may participate in the adjustment market if there is an energy deviation or participate in real-time markets if close to real-time. Furthermore, depending on the market framework, the EVPLA may have to pay the penalty when they fail to fulfil the necessary obligations in market participation and cause energy deviations [15]. Since the energy market structures of each country are different, they are operated with different rules and there may be changes in their main structures. For example, generally, the Market Operator and the System Operator are different entities; however, it can be a single entity in some markets such as Pennsylvania Jersey Maryland (PJM) Interconnection and ISO New England. Thus, each such market types also pose different challenges as well as opportunities for new market players like EVPLAs.

1.2. Relevant Literature

Researchers and investors have been considering that batteries of EVs can be used in various applications considering them as a flexible load and a source. However, managing multiple EVs is a serious business, and their highly distributed participation in the electricity market is challenging to manage. This problem can be tackled by introducing a new market player as a medium namely EVPLA that includes EVPLs as mentioned above.
In this way, a significant opportunity can be obtained for participation in the electricity market for economic charging. Therefore, there has been considerable interest in the involvement of EVs in the electricity market recently.

Wang et al. [16] proposed a model to maximize the profit of an EV charging station by optimizing a combination of admissions controls, electricity pricing, and charging schedules for EVs. In contrast to existing EV charging operation models, the proposed concept comprised a structure to provide a balance between the delay penalty, electricity price, and EV admissions rate. According to the results of the analysis, the proposed method was able to achieve between 330% and 531% higher profit than the commonly used means. However, an absolute minimum charging rate for EVs was not determined and energy markets were not included. Chung et al. [17] proposed a model for an aggregator taking into account the minimum cost of charging and user convenience. Compared to the other studies in the literature, the proposed model reduced the charging time by 30%. However, in this study, there was no precise minimum level for the comfort of EV owners. Besides, there were no energy markets, and the uncertainties of electric vehicle behavior and electricity price uncertainty were not taken into account. Clairand et al. [18] suggested a model allowing the EVs to be charged at minimum cost while meeting the technical limits associated with the distribution system operator and the transmission system operator where EV owners could determine the charging duration based on their needs. According to the results obtained from the case study in Quito, Ecuador, a profit increase about 5% - 50% compared to the uncoordinated charge was obtained. However, the mentioned study included neither energy markets nor not the minimum charge rate for the comfort of EV owners in this study. Ensslen et al. [19] devised an electricity tariff aimed at shifting the load to cope with the difficulties in the power system due to the increasing number of EVs and the proposed structure was tested in the French and German energy markets. From the results obtained, it was found out that the incentive mechanism was exceptionally suitable to provide load flexibility. However, this study disregarded the reserve market, the comfort of EV owners, and the parking lot (PL) concept.

Sortomme and El-Sharkawi [20] introduced a structure including an optimal bidding strategy to the regulation and reserve market to maximize the profits of the EV aggregators and to increase the benefits of utility and EV owners. This study did not consider the uncertainty related to the departure times of EVs from PL. In [21], Vagropoulos and Bakirtzis proposed a stochastic optimization model that the EVPLA offered to the DA and the regulation market. It was concluded that uninstructed deviations played an essential role in determining the bid amount. Baringo and Amaro [22] discussed the bidding strategy problem of an EV aggregator participating in the DA market. It was stated that the proposed model could be used for the introduction of EV aggregators to the DA market, and additionally the cost of charging was significantly reduced by the aid of the proposed concept. Neyestani et al. [23] devised a model in which the EVPL could operate in the energy and reserve market through the distribution system operator. The mentioned model performed operations between the distribution system operator and the PL in a balanced way in terms of their profits.
In [24], Wu et al. developed a model submitting the optimum bidding strategy for the EVPLA to DA and ancillary service markets taking into account the integration of renewable energy sources into the grid where conditional-value-at-risk was used to measure risks in the model. Vayá and Andersson [25] proposed an approach that the EV aggregator offered the DA market to meet the charging demand of EVs. It was assumed that the EV aggregator had a potential impact on market prices, and other consumer offers were based on an estimation using historical data. The EV aggregator only offered to purchase electricity, and in that study, the issue of selling back to the grid was not discussed.

Bessa et al. [26] devised a structure in which the EV aggregator offered to buy energy from the DA market and sell energy to the reserve market and the mentioned model was tested with the 2-year data received at Iberian Market. The objective was to charge electric vehicles most economically; however, the mentioned study did not take into account the comfort of EV owners. Sarker et al. suggested a structure maximizing the profit by the EV aggregator's participation in energy and reserve market in [27]. The authors took into account the expected acceptance possibilities and the up and down regulation possibilities in the market offers. Besides, the propounded model considered battery degradation of EVs. It was also stated that the profit from the reserve market was higher than the energy market. Moghaddam and Akbari [28] presented an offering model that the EVPLA incorporated into the DA and reserve markets for profit maximization. The uncertain expressions in the problem were modelled in a stochastic and robust manner. However, it is worth underlining that the selling of energy from the V2G was not realized in the mentioned study. Soares et al. [29] created an optimum bidding strategy model for the EVPLA to participate in the frequency-controlled normal operation reserve service (FCR-N) and DA market in Denmark. The propounded model aimed to increase the expected revenue by taking into account the penalties that may arise from market participation. The authors also tested the mentioned model in the project named as PARKER. Iria et al. [30] proposed a stochastic model in which the EV aggregator managed smart homes and their flexible loads as well as EVs, for the DA and reserve market. The objective was to minimize the cost of electricity trade in both energy and real-time markets. It was also expressed that a significant reduction in carbon emissions could be achieved with renewable resources and flexible load and production units. Chen et al. [31] designed a business model to maximize the profits of EV owners where the EV aggregator joined the spot markets and the regulation market. The proposed model optimized the problem by considering energy demands and market conditions; moreover, the bidding strategy was formulated in a stochastic structure considering market prices and EV behaviors.

Shafie-khah et al. [32] developed a model for short-term and long-term periods in which the EV aggregator participated in the energy and reserve markets and the charging costs of EVs, the cost of charging infrastructure, inverters, and management systems were considered in the problem structure. In that study, it should be stated that the satisfaction of the EV owners was addressed as cheaply charging of the EV.
Many more studies that cannot be referred all here also provided significant contributions in the field of using EVs based operational flexibility in electricity markets. However, stochasticity regarding EV owner preferences and behaviors as well as market conditions, together with the prosumer role of EVs and comfort satisfaction for EV owners, have not been addressed in a single study yet to the best knowledge of the Authors.

1.3. Contributions and Organization

This study proposes a mixed-integer linear programming model in which the EVPLA participates in the DA and reserve markets, intending to minimize the total cost and manage the batteries of the EVs considering the comfort of the EV owners by sustaining the minimum desired departure charge level of EVs owners. EVs’ arrival and departure times and their behavior during the day are unpredictable. Furthermore, DA and reserve market prices vary based on market participants and their daily capacity. High volatility is not desirable for market participants because of the unknown profit or cost. In order to address the uncertainties mentioned above, a stochastic approach has been adopted in the proposed model.

Accordingly, the novelties of this study are twofold:

- The EV aggregator that manages EVPLs participates in the DA market for both energy purchasing and selling, and it bids the reserve market as a prosumer. The arrival time of the vehicles to the PL, the battery energy levels during the arrival, the departure time from the PL, and the electricity prices in the DA and reserve markets are uncertain. This problematic situation is handled by considering scenarios for all uncertain parameters regarding EV owner behaviors and electricity unit prices (DA, reserve) together with the consideration of both DA and reserve markets based benefit possibilities from the EVPLA point of view for the first time in the literature to the best knowledge of the Authors.

- The EV aggregator that participated in the energy markets is willing to discharge as many EVs as possible to increase its profit. However, this may cause problems for EV owners. For this reason, in this study, the comfort of the vehicle owners is taken into account by providing at least a predetermined energy level at the departure time, which is a vital operational concept considered firstly from this point of view in the literature regarding EVPLA participation in energy markets.

In short, the innovation of the study is the evaluation of all of the characteristics mentioned above together, such as handling EV behavior and uncertainties of electricity prices stochastically, the comfort level of EV owners, and participation of the EVPLA in the DA and reserve market. A study that includes all of these characteristics is presented in this paper for the first time in the literature.

Table 1 gives a detailed comparison of this manuscript with the existing literature to further depict the difference of the proposed concept.
Table 1. Taxonomy of the proposed methodology compared to representative literature studies

<table>
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The rest of the paper is organized as follows. Section II includes details of the mathematical model of the proposed structure. Then, the results of the study along with detailed case studies are evaluated in Section III. Finally, Section IV comprises a discussion of the overall results of the study and future studies.

2. Methodology

2.1. An Overview of the Proposed Structure

Figure 1 illustrates the proposed system structure. As it can be observed in the mentioned figure, the EVPLA participates in the DA and reserve market for the related PLs and performs energy purchasing and/or selling transactions with Market Operator and Independent System Operator. The EVPLA aims to minimize the total cost during the daily operation of the EVPLs. In this study, the EVPLA bids to Independent System Operator, and it also bids and offers to Market Operator. Besides, the EVPLA is considered as a price-taker within the considered concept. To serve for this purpose, EVPLA manages charging/discharging operations of EVs according to accepted energy transactions considering the SoE of EVs in terms of the comfort of EV owners. The flowchart for the structure in which the EVPLA offers/bids to the electricity markets, taking into account the comfort of the EV owners, is given in Fig. 2.
Fig. 1. The proposed structure that the EV aggregator participates in DA and reserve markets for cost minimization.

Fig. 2. Flowchart of bidding and offering strategy according to EV owners’ comfort.
2.2. Mathematical Formulation

Equation (1) describes the objective function to minimize the total cost. It strives to increase the income by discharging the energy from EVs to the grid as much as possible while buying the energy for charging the EVs as cheap as possible by considering the comfort of the EV owners. Therefore, it offers/bids to DA and reserve markets. The expansion of each expression in the function is given below.

\[
\min \left[ C_{buy}^{DA} - I_{sell}^{DA} - I_{res\_consum}^{Res} - I_{res\_prod}^{Res} \right]
\]  

Equations (2) and (3) are the cost statements of the energy purchased from the DA market and profit of the energy sold to the DA market, respectively. These expressions are obtained by multiplying the energy offer/bidding to the DA market and the unit price of the DA energy for purchasing/selling. Since the behavior of EVs and the unit energy price depend on the scenarios, multiplication with \( f_s \) and \( k_w \) provides the impacts of probabilities of related scenarios.

\[
C_{buy}^{DA} = \sum_s \sum_w \sum_h (f_s \cdot k_w \cdot P_{W,h}^{DA} \cdot E_{s,h}^{DA,\text{buy}})
\]  

\[
I_{sell}^{DA} = \sum_s \sum_w \sum_h (f_s \cdot k_w \cdot P_{W,h}^{DA} \cdot E_{s,h}^{DA,\text{sell}})
\]  

The profit expressions as consumer and producer in the reserve market participation are given by (4) and (5), respectively.

\[
I_{res\_consum}^{Res} = \sum_s \sum_w \sum_h (f_s \cdot k_w \cdot P_{W,h}^{Res} \cdot E_{s,h}^{Res,\text{consum}})
\]  

\[
I_{res\_prod}^{Res} = \sum_s \sum_w \sum_h (f_s \cdot k_w \cdot P_{W,h}^{Res} \cdot E_{s,h}^{Res,\text{prod}})
\]  

The maximum upward reserve capacity of the PL in the case of consumers is determined by (6). Here, (6) states that the amount of reserve offered as a consumer should be less than the sum of the energy that all EVs in the EVPLs are charged in real-time. The maximum downward reserve capacity is determined by (7). Inequality (7) states that the amount of reserve offered as a consumer should be less than the energy difference between the consumed energy for charging all EVs fully and the actual consumed energy. Similarly, in the case of the producer, the maximum upward reserve capacity is determined by (8). Herein, (8) states that the amount of reserve offered as a producer should be less than the sum of the energy for realized discharging operation of all EVs in the EVPLs. The maximum downward reserve capacity is determined by (9). Inequality (9) states that the amount of reserve offered as a producer should be less than the energy difference between the maximum energy in the case of completely discharging of all EVs, and the energy caused by the realized discharging operation of all EVs in the EVPLs. Upward reserve capacity limits the reserve up to the maximum amount of energy used in real-time while downward reserve capacity limits the reserve up
to the maximum amount of unused energy in real-time. The EV aggregator proposes to increase its production (discharging of EVs) between $h_d$ and $h_{end}$ hours and to decrease its consumption outside these hours in the reserve market.

\[
E_{Res,\text{consum}}^{s,h} \leq E_{s,h}^{EVs,\text{consum}}, \quad \forall S, h
\]  
\[
E_{Res,\text{consum}}^{s,h} \leq TR_{s,h}^{EV,\text{ch}} - E_{s,h}^{EVs,\text{consum}}, \quad \forall S, h
\]  
\[
E_{Res,\text{prod}}^{s,h} \leq E_{s,h}^{EVs,\text{prod}}, \quad \forall S, h
\]  
\[
E_{Res,\text{prod}}^{s,h} \leq TR_{s,h}^{EV,\text{disch}} - E_{s,h}^{EVs,\text{prod}}, \quad \forall S, h
\]

The expressions in (8) and (9) denoting the sum of the maximum charging and discharging powers of the EVs in the EVPL are given in (10) and (11), respectively.

\[
TR_{s,h}^{EV,\text{ch}} = \sum_{p} \sum_{v} \sum_{t} CP_{p,v}^{EV} \cdot \Delta T, \quad \forall S, h, \quad t \in [T_{p,v,s}^{a}, T_{p,v,s}^{d}) \text{ and } t \in \Delta t
\]  
\[
TR_{s,h}^{EV,\text{disch}} = \sum_{p} \sum_{v} \sum_{t} DP_{p,v}^{EV} \cdot DE_{p,v}^{EV} \cdot \Delta T, \quad \forall S, h, \quad t \in [T_{p,v,s}^{a}, T_{p,v,s}^{d}) \text{ and } t \in \Delta t
\]

The balance between the energy purchased from the DA market, the energy offered to the reserve market, and the charging energy of EVs is given in (12). Similarly, the power balance between the energy sold to the DA market, reserve market, and the discharging energy of EVs is given in (13).

\[
E_{s,h}^{DA,\text{buy}} - E_{s,h}^{Res,\text{consum}} = E_{s,h}^{EVs,\text{consum}}, \quad \forall S, h
\]  
\[
E_{s,h}^{DA,\text{sell}} + E_{s,h}^{Res,\text{prod}} = E_{s,h}^{EVs,\text{prod}}, \quad \forall S, h
\]

Equations (14) and (15) describe the total purchased and sold energies during hour $h$, respectively. These expressions are equal to the sum of the energies in the sub-hour intervals for each hour.

\[
E_{s,t}^{EVs,\text{consum}} = \sum_{t} E_{s,t}^{EVs,buying}, \quad \forall S, h, \quad t \in \Delta t
\]  
\[
E_{s,t}^{EVs,\text{prod}} = \sum_{t} E_{s,t}^{EVs,selling}, \quad \forall S, h, \quad t \in \Delta t
\]

The total energy consumption during time $t$ is equal to the sum of the energy consumption of each EV as given in (16). Likewise, the total sold energy during time $t$ is equal to the sum of the discharged energy from each EV as depicted in (17).

\[
E_{s,t}^{EVs,buying} = \sum_{p} \sum_{v} E_{p,v,s,t}^{EV,\text{ch}}, \quad \forall S, t
\]
Equations (18) and (19) define that the charging and discharging power cannot be higher than the charging and discharging capacity, respectively. \( u_{p,v,s,t}^{EV} \) is a binary decision variable and is used to prevent simultaneous charging and discharging operation.

\[
P_{p,v,s,t}^{EV,\text{ch}} \leq (CR_{p,v}^{EV} \cdot u_{p,v,s,t}^{EV}), \quad \forall p, v, s, \quad t \in [T_{p,v,s}^a, T_{p,v,s}^d]
\]

\[
P_{p,v,s,t}^{EV,\text{disch}} \leq (DR_{p,v}^{EV} \cdot DE_{p,v}^{EV} \cdot (1 - u_{p,v,s,t}^{EV})), \quad \forall p, v, s, \quad t \in [T_{p,v,s}^a, T_{p,v,s}^d]
\]

The prevention of charging and discharging when the EVs are not in the PL is provided by (20) and (21), respectively.

\[
p_{p,v,s,t}^{EV,\text{ch}} = 0, \quad \forall s, \quad t \notin [T_{p,v,s}^a, T_{p,v,s}^d]
\]

\[
p_{p,v,s,t}^{EV,\text{disch}} = 0, \quad \forall s, \quad t \notin [T_{p,v,s}^a, T_{p,v,s}^d]
\]

The condition of preventing the charging of EVs between the periods \( t_{st} \) and \( t_{end} \), and similarly preventing the discharging of EVs outside of this period is provided by (22) and (23), respectively. The reason for these constraints is that energy can be sold back to the grid only between these periods.

\[
p_{p,v,s,t}^{EV,\text{ch}} = 0, \quad \forall s, \quad t \in [t_{st}, t_{end}]
\]

\[
p_{p,v,s,t}^{EV,\text{disch}} = 0, \quad \forall s, \quad t \notin [t_{st}, t_{end}]
\]

Equation (24) indicates the SoE expression of EVs for each time interval \( t \). The SoE expression is obtained by adding/subtracting the charging/discharging energy in this range to/from the SoE level in the previous time period.

\[
SoE_{p,v,s,t}^{EV} = SoE_{p,v,s,t-1}^{EV} + CE_{p,v}^{EV} \cdot p_{p,v,s,t}^{EV,\text{ch}} \cdot \Delta T - p_{p,v,s,t}^{EV,\text{disch}} \cdot \Delta T, \quad \forall p, v, s, \quad t \in [T_{p,v,s}^a, T_{p,v,s}^d]
\]

Throughout the simulation studies, the fact that the SoE of the EVs should always be smaller than the maximum energy capacity is provided by (25). Similarly, (26) ensures that the charge state of the EVs is greater than the minimum level in all time periods.

\[
SoE_{p,v,s,t}^{EV} \leq E_{p,v}^{EV,\text{max}}, \quad \forall p, v, s, \quad t \in [T_{p,v,s}^a, T_{p,v,s}^d]
\]

\[
SoE_{p,v,s,t}^{EV} \geq E_{p,v}^{EV,\text{min}}, \quad \forall p, v, s, \quad t \in [T_{p,v,s}^a, T_{p,v,s}^d]
\]

Equation (27) clarifies that the SoE level of each EV arrives in the EVPL is equal to the initial energy level for the period just before the plug-in.

\[
SoE_{p,v,s,t}^{EV} = SoE_{p,v}^{EV,\text{ini}}, \quad \forall p, v, s, \quad t = [T_{p,v,s}^a]
\]
To take into account the comfort of EV owners, (28) is introduced into the devised model. Here, SoE at the departure time of EV is equal to the desired value or higher than it. Moreover, $g$ value is the coefficient between 0 and 1, used to set the desired amount. EV owners’ comfort means that the minimum level of energy required for an EV to be charged while leaving the PL. Taking this value into account, EV aggregator is offering and bidding in the electricity market. As a result, the EV departs from the PL with at least this SoE level. It should be emphasized that the SoE level of EVs can take a value greater than this determined level at the departure time if economical.

$$\text{SoE}_{\text{EV}}^\text{p,v,s,t} \geq E_{\text{EV}}^\text{max,p,v} \cdot g, \quad \forall p, v, s, \quad t = \left[ T_{d}^d \right]$$

(28)

Equations (29) and (30) denote energy consumption and generation during $t$ to $(t + 1)$, respectively. Here, the trapezoid rule gives the approximate energy expression, which is more accurate than operations with $P_{\text{EV},\text{ch}}^{k,m,s,t}$ and $P_{\text{EV},\text{disch}}^{k,m,s,t}$.

$$E_{\text{EV},\text{ch}}^{p,v,s,t} = ((P_{\text{EV},\text{ch}}^{p,v,s,t} + P_{\text{EV},\text{ch}}^{p,v,s,t+1})/2) \cdot \Delta T, \quad \forall p, v, s, \forall t$$

(29)

$$E_{\text{EV},\text{disch}}^{p,v,s,t} = ((P_{\text{EV},\text{disch}}^{p,v,s,t} + P_{\text{EV},\text{disch}}^{p,v,s,t+1})/2) \cdot \Delta T, \quad \forall p, v, s, \forall t$$

(30)

3. Test and Results

In this study, the problem that the EVPLA aims to minimize the total cost in terms of EVPLA, EV owners, and also EVPL by taking into consideration the comfort of the EV owners and participating in DA and secondary reserve markets is modelled and the proposed methodology is tested in GAMS v.24.1.3. As the solver, the commercial CPLEX v12. solver is used. The problem can be solved in 3.25 seconds in a Dual Core Laptop with 1.7 GHz CPU and 6 GB RAM. The model is tested on a daily time horizon and at 5-minute granularities. Different case studies are analyzed below to prove the efficiency of the proposed methodology.

3.1. Input Data

The uncertainties regarding the behavior of EV, DA, and secondary reserve market prices are considered via a scenario-based stochastic approach. Four different scenarios for the behavior of EVs (Arrival time, departure time, and SoE of EV at arrival time) and 100 different scenarios for DA and secondary reserve market prices are evaluated. Figure 3 shows the arrival and departure time for scenario 1 of 100 EVs in EVPL1. Besides, the DA market and reserve market prices consisting of 100 scenarios for Turkey, Finland, and the USA are given in Fig. 4-9, respectively. It is assumed that the EVPLA offers to buy/sell energy from/to the DA market and offers for up-regulation service in the secondary reserve market. Up-regulation can be explained as increasing the electricity sold to the grid or reducing consumption. The EV aggregator only sells energy to the grid in time interval of $t_{u}$ and $t_{end}$. It participates in this time interval for DA selling and to increase the amount of selling to the reserve market.

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Fig. 3. The arrival and departure times for 100 EVs in EVPL1 according to Scenario 1.

Fig. 4. Daily DA market prices in Turkey (100 scenarios).

Fig. 5. Daily secondary reserve market prices in Turkey (100 scenarios).
Fig. 6. Daily DA market prices in Finland (100 scenarios).

Fig. 7. Daily secondary reserve market prices in Finland (100 scenarios).

Fig. 8. Daily DA market prices in USA-PJM (100 scenarios).
Outside this time interval, the EV aggregator participates in the DA market to buy electricity, and it participates in reducing electricity consumption to the reserve market. In the system to be tested to create the loads, there are 40 EVs from each of the ten vehicles, each of which has different characteristics comprising a total of 400 EVs. The characteristics of these EVs can be found in [33] - [42].

3.2. Simulation Results

In order to test and validate the proposed system, 18 different case studies stated as follows are created and tested:

- **Case-1**: EVPLA is involved in the Turkey DA market. Also, EVs depart with at least an 80% charging level.
- **Case-2**: EVPLA is involved in the Turkey DA market. Also, EVs depart with at least a 90% charging level.
- **Case-3**: EVPLA is involved in the Turkey DA market. Also, EVs depart as fully charged.
- **Case-4**: EVPLA is involved in the Finland DA market. Also, EVs depart with at least an 80% charging level.
- **Case-5**: EVPLA is involved in the Finland DA market. Also, EVs depart with at least a 90% charging level.
- **Case-6**: EVPLA is involved in the Finland DA market. Also, EVs depart as fully charged.
- **Case-7**: EVPLA is involved in Turkey DA and reserve market. Also, EVs depart with at least an 80% charging level.
- **Case-8**: EVPLA is involved in Turkey DA and reserve market. Also, EVs depart with at least a 90% charging level.
- **Case-9**: EVPLA is involved in Turkey DA and reserve market. Also, EVs depart as fully charged.
- **Case-10**: EVPLA is involved in Finland DA and reserve market. Also, EVs depart with at least an 80% charging level.
• **Case-11:** EVPLA is involved in Finland DA and reserve market. Also, EVs depart with at least a 90% charging level.

• **Case-12:** EVPLA is involved in Finland DA and reserve market. Also, EVs depart as fully charged.

• **Case-13:** EVPLA is involved in the USA-PJM DA market. Also, EVs depart with at least an 80% charging level.

• **Case-14:** EVPLA is involved in the USA-PJM DA market. Also, EVs depart with at least a 90% charging level.

• **Case-15:** EVPLA is involved in the USA-PJM DA market. Also, EVs depart as fully charged.

• **Case-16:** EVPLA is involved in USA-PJM DA and reserve market. Also, EVs depart with at least an 80% charging level.

• **Case-17:** EVPLA is involved in USA-PJM DA and reserve market. Also, EVs depart with at least a 90% charging level.

• **Case-18:** EVPLA is involved in USA-PJM DA and reserve market. Also, EVs depart as fully charged.

Table 2 encapsulates the total cost results of evaluated case studies as a result of the objective function. The price signals of Turkey and USA markets are converted to be used in EUR. The worst result is in the Case-6, where the EV aggregator only participates in the Finland DA market and fully charges the EVs batteries. In this case, the total cost is EUR 250,287. The best result was obtained in Case-7, Case-8, and Case-9 as by -160,626. As the RE market prices are reasonably high compared to the DA prices in Turkey, the result is negative. Although the minimum charging levels are changed, it is found that the EVs are fully charged for 3 case studies to increase profit. When the participation in DA and reserve markets is provided for three countries, more profit is obtained than the profit obtained by participating only in DA markets.

In the cases of considering only the Finland markets, more profit is achieved by DA and reserve markets for the same minimum charging level compared with only the DA market. A profit of EUR 44,558 compared to Case-4 and Case-10, a profit of EUR 44,819 compared to Case-5 and Case-11, a profit of EUR 41,595 compared to Case-6 and Case-12 was achieved. Furthermore, it can be observed that profit is decreased by increasing the minimum SoE level of EVs at the departure time for the same market participation.

In the cases of taking into account only the Turkey DA market, it is observed that profit decreases as the minimum energy level are increased. However, if the participation in the reserve markets is also realized, the EVs are fully charged due to the high RE market prices, and the profit for these cases remains constant.
Table 2 Comparison of results obtained from case studies (Costs [EUR])

<table>
<thead>
<tr>
<th>Market Participation</th>
<th>Country</th>
<th>(% Minimum SoE of EVs at Departure Time)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>80%</td>
</tr>
<tr>
<td>DA</td>
<td>Turkey</td>
<td>19,322</td>
</tr>
<tr>
<td></td>
<td>Finland</td>
<td>128,914</td>
</tr>
<tr>
<td></td>
<td>USA</td>
<td>69,282</td>
</tr>
<tr>
<td>DA + Reserve</td>
<td>Turkey</td>
<td>-160,626</td>
</tr>
<tr>
<td></td>
<td>Finland</td>
<td>84,356</td>
</tr>
<tr>
<td></td>
<td>USA</td>
<td>56,337</td>
</tr>
</tbody>
</table>

A profit of EUR 179,948 compared to Case-1 and Case-7, a profit of EUR 187,708 compared to Case-2 and Case-8, a profit of EUR 196,022 compared to Case-3 and Case-9 is achieved. Furthermore, the profit was decreased by increasing the minimum charge level of EVs at departure time when EV aggregator participates only DA market.

If only USA markets are considered, more profit is achieved by DA and reserve markets for the same minimum charging level compared with only the DA market. A profit of EUR 12,945 compared to Case-13 and Case-16, a profit of EUR 13,166 compared to Case-14 and Case-17, a profit of EUR 13,305 compared to Case-15 and Case-18 is achieved. Furthermore, it can be observed that profit is decreased by increasing the minimum charging level of EVs at departure time for the same market participation as in Finland and Turkey. Judging by the results for the USA, they are between obtained for Turkey and Finland in each case. Considering just the DA market participation in Turkey, the profit decreases with increasing minimum energy level. However, if the participation in the reserve markets is also ensured, the EVs have reached the maximum SoE level due to the high reserve market prices, and the profit remains constant for the 3 case studies. It should be underlined that the obtained results are only for 400 EVs and also be noted that the EV batteries are not completely empty when they arrive at the PL.

The amount of energy offered/bidden to DA and reserve markets in each case study is given in Table 3. The most significant energy amount to selling to the DA market carries out with the Finland DA market participation in Case 4 with 1441,965 kWh. The most significant energy amount to buy from the DA market carries out with DA and reserve market participation in Turkey in Case-7, Case-8, and Case-9 with 15846,03 kWh. The most significant reserve amount to market as a producer carries out with DA and reserve market participation in Turkey in Case-7, Case-8, and Case-9 with 1413.133 kWh. The most significant reserve amount to market as a consumer carries out with DA and reserve market participation in Turkey in Case-7, Case-8, and Case-9 with 7923,017 kWh as Turkey reserve prices are moderately higher compared to other evaluated markets.
### Table 3: Comparison of Results Obtained from Case Studies

<table>
<thead>
<tr>
<th>Case Studies</th>
<th>Country</th>
<th>Market Participation</th>
<th>Comfort Level of EV Owners</th>
<th>Day-Ahead</th>
<th>Reserve</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bid Amount [kWh]</td>
<td>Offer Amount [kWh]</td>
</tr>
<tr>
<td>Case-1</td>
<td>Turkey</td>
<td>DA</td>
<td>%80</td>
<td>198,6456</td>
<td>3486,876</td>
</tr>
<tr>
<td>Case-2</td>
<td>Turkey</td>
<td>DA</td>
<td>%90</td>
<td>75,12497</td>
<td>4675,769</td>
</tr>
<tr>
<td>Case-3</td>
<td>Turkey</td>
<td>DA</td>
<td>%100</td>
<td>43,1353</td>
<td>6037,007</td>
</tr>
<tr>
<td>Case-4</td>
<td>Finland</td>
<td>DA</td>
<td>%80</td>
<td>1441,965</td>
<td>4864,516</td>
</tr>
<tr>
<td>Case-5</td>
<td>Finland</td>
<td>DA</td>
<td>%90</td>
<td>1296,542</td>
<td>6029,14</td>
</tr>
<tr>
<td>Case-6</td>
<td>Finland</td>
<td>DA</td>
<td>%100</td>
<td>1154,962</td>
<td>7268,948</td>
</tr>
<tr>
<td>Case-7</td>
<td>Turkey</td>
<td>DA + RM</td>
<td>%80</td>
<td>-</td>
<td>15846,03</td>
</tr>
<tr>
<td>Case-8</td>
<td>Turkey</td>
<td>DA + RM</td>
<td>%90</td>
<td>-</td>
<td>15846,03</td>
</tr>
<tr>
<td>Case-9</td>
<td>Turkey</td>
<td>DA + RM</td>
<td>%100</td>
<td>-</td>
<td>15846,03</td>
</tr>
<tr>
<td>Case-10</td>
<td>Finland</td>
<td>DA + RM</td>
<td>%80</td>
<td>260,167</td>
<td>9474,903</td>
</tr>
<tr>
<td>Case-11</td>
<td>Finland</td>
<td>DA + RM</td>
<td>%90</td>
<td>-</td>
<td>11148,68</td>
</tr>
<tr>
<td>Case-12</td>
<td>Finland</td>
<td>DA + RM</td>
<td>%100</td>
<td>-</td>
<td>11892,97</td>
</tr>
<tr>
<td>Case-13</td>
<td>USA</td>
<td>DA</td>
<td>%80</td>
<td>552,772</td>
<td>3879,261</td>
</tr>
<tr>
<td>Case-14</td>
<td>USA</td>
<td>DA</td>
<td>%90</td>
<td>268,386</td>
<td>4889,909</td>
</tr>
<tr>
<td>Case-15</td>
<td>USA</td>
<td>DA</td>
<td>%100</td>
<td>68,4735</td>
<td>6065,083</td>
</tr>
<tr>
<td>Case-16</td>
<td>USA</td>
<td>DA + RM</td>
<td>%80</td>
<td>82,100</td>
<td>6841,498</td>
</tr>
<tr>
<td>Case-17</td>
<td>USA</td>
<td>DA + RM</td>
<td>%90</td>
<td>27,398</td>
<td>7984,912</td>
</tr>
<tr>
<td>Case-18</td>
<td>USA</td>
<td>DA + RM</td>
<td>%100</td>
<td>90,546</td>
<td>8990,275</td>
</tr>
</tbody>
</table>

RM = Reserve Market

A sample group of results for Scenario 1 in Case-10 where EVPLA participates in the DA and reserve market in Finland, also the comfort level of EV owners is least 80%, the offer and bid amounts are given in Fig. 10. The energy is sold to the DA market only at 12 pm and a reserve is also offered as a producer in time interval $h_{ur}$ and $h_{end}$. At 1 pm, the power generated is fully offered as a reserve and the highest power consumption is observed at 3 pm. Apart from 10 pm and 11 pm, it is obviously seen the reserve in the case of the consumer is offered equally to the power consumed.
Fig 10. Offers/bids to the DA and reserve markets in Case-10 for Scenario 1.

In Case-3 and Case-9, the hourly power quantities offered/bidden to the markets are given in Fig. 11, where EVs participate in only DA or DA and reserve markets at 100% comfort level. In Case 3, at 12 pm, a tiny amount is bidden to the DA market. In Case-9, there is no bid to the DA market as it is not profitable. Furthermore, in Case-9, a reserve offer was made as much as the amount of consumption for each hour if there is consumption. In Case-3, only DA market participation is realized. The amount of power offered to charge EVs in the DA market is less than in Case-9.

In Case-17 and Case-18 where EVPLA participates in the DA and reserve market in the USA, and the comfort level of EV owners is 80% and %100, the offer and bid amounts for Scenario 2 are given in Fig. 12. It can be deduced from the mentioned figure that the results for Case-17 and Case-18 are very close to each other at some hours. Since EVs are fully charged in Case-18, equal or more energy is bought from the DA market than Case-17. More reserve is offered as a producer in Case-17. It is observed that the results for both cases are close to each other until 12 pm, but the results differ after the possibility of energy selling to the grid.

Fig 11. The power amounts in Case-3 and Case-9 for Scenario-3.
The SoE of the EV WO8 [33] in EVPL 1 in Case-2, Case-5, Case-8, and Case-11 for Scenario 1 is given in Fig. 13 to reveal how different cases affect the comfort of EV owners. In these cases, it is desirable to leave of EVs with at least a 90% SoE level. In Case-5, Case-8, and Case-11, it is observed that the EV is slightly discharged between 12:00-14:00, and EV reaches a 90% charge rate at departure time. Also, it is observed that EV is fully charged in Case-8, participating in Turkey DA and reserve market. This is due to the higher reserve market prices compared to the DA prices in Turkey.

Figure 14 presents the offer, and bid amounts for Case-3, Case-6, and Case-15 where the comfort level of the EVs is desired to be 100%, and participation is made only in the DA market. Considering the three countries, the highest-selling transaction to the DA market is in Finland, and USA and Turkey follow Finland case.

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**Fig. 12.** The power amounts in Case-17 and Case-18 for Scenario-2.

**Fig. 13.** SoE of EV WO8 in EVPL 1 in Case-2, Case-5, Case-8 and Case-11 for Scenario 1.
As the energy is bought only from the DA market, the highest energy amount drawn from the grid occurs in Finland between 4 pm and 5 pm. Overall, EVs in Turkey and the USA reach the desired charging level earlier, and the charging patterns are more balanced than Finland.

Cases that EVPLA participates only in Turkey and Finland DA markets and the EV owners' comfort levels vary as 80%, 90% and 100%, the power consumption of the EVs for charging is given in Figure 15. It is observed that the EVs are not charged between 12 pm and 2 pm since they are discharging. As a result of the increase in desired comfort level during the same market participation, the power consumed by the EVs increases. Approximately at time intervals, 7 am-12 pm, 3 pm-4 pm, 6 pm-8 pm during the participation in the Turkey electricity market, EVs consume more. Approximately at other time intervals, the amount of power consumed through the involvement of the Finland electricity market is more considerable.

In Case 4, in which EVPLA participates in the Finland DA market and in Case 10, in which EVPLA participates in Finland DA and reserve markets, totally consumed power by the EVs for Scenario 1 is given in Fig. 16 and total discharged energy from EV batteries between 12 pm-2 pm for Scenario 1 is given in Fig. 17. In Case 4, where EVPLA participates in DA market in the 14:00-15:40 time interval, there is a significant reduction in the amount of power consumed by EVs. From another point of view, in case of participation in the DA and reserve markets (Case-10), EVs are charged more. In addition, when the amount of energy discharged and sold from EVs is analyzed, it is observed that EVs are discharged more in Case 10, where DA and reserve market participation is realized.
Fig. 15. The power consumed for charging EVs in Case-1, Case-2, Case-3, Case-4, Case-5 and Case-6 for Scenario-4.

Fig. 16. The power consumed for charging EVs in Case-4 and Case-10 for Scenario 1.

Fig. 17. The energy sold from EVs in Case-4 and Case-10 for Scenario 1.
4. Conclusion

There is an intense interest in EVs regarding the adverse impacts of fossil fuels on environment and the limited resources of these fuels that may impose risks for a future sustainable supply to different sectors, including transportation which is currently a major fossil fuel consumer. Considering that the number of EVs are increasing day by day and there is a strong governmental and industrial support to accelerate the mentioned increase, many operational problems such as congestion in the power grid are likely to be faced. However, since EVs might be considered as a flexible load, they can even help to eliminate imbalances between production and consumption. EVPLs can provide cheap charging to EV owners by a properly coordinated charging management strategy for EVs. An EV owner cannot directly participate in any energy markets and perform proper scheduling for charging EVs inexpensively. In this respect, the EVPLAs indirectly on behalf of EVs can participate in the electricity markets and make a profitable transaction. This work proposed an optimization model in which an EVPLA participating in day-ahead and secondary reserve markets aimed to minimize the total cost of charging EVs. The EVPLA also took into account the comfort of the EV owners while performing these transactions. The level of comfort was expressed using the minimum desired SoE level of EV owners at the departure time from the EVPL, which is a vital issue for an EV owner to prevent range anxiety after leaving the EVPL. Arrival and departure times of EVs, SoE at arrival time, DA, and reserve market prices were considered as uncertain parameters. These uncertainties may create significant problems and risks for the EVPLA in terms of participation in the energy market and these data were accordingly modelled in a stochastic manner. The market prices from Turkey, Finland, and USA-PJM were used to test the proposed model in this study. According to the results of the study, EV aggregators could make a significant profit if they participate in DA and reserve markets. When the participation in both DA and reserve market was realized, the profit rate increased further comparing to only DA market participation. It can be stated that the best results were obtained with Turkey DA and secondary reserve market participation. In this case study, it was observed that the EVs are fully charged regardless of the comfort level of EV owners. Apart from this case study, it was observed that as the comfort level of the EVs increased, the obtained profit decreased. It should be noted that the test results were only for 400 EVs and that the EVs did not come to the EVPL with an empty battery. It should lastly be noted that, the profit rates would probably change for an EV aggregator with a larger load group. In future studies, bilateral agreements between EV owners and EVPL or EV owner and EVPLA may be considered for sharing profits and giving priority to charging. A bidding strategy can be developed by considering also the battery wear and tear costs. The participation in the regulation market can also be achieved within the electricity market. In addition, the possible distributed generation availability within EVPL such as PV power generation systems in canopy form can be evaluated.
Acknowledgment

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