Learning Portfolio Optimization of Electric Vehicle Virtual Power Plants in Smart Sustainable Electricity Markets: A ML-based Intelligent Agent Approach

Master Thesis Proposal

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October, 2018

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1 Introduction

1.1 Research Motivation

The global climate change is one biggest challenges of our time. Carbon emissions need to be reduced and the shift to sustainable energy sources is inevitable. But integration of renewables into the electricity grid proves to be difficult: Solar and wind energy is intermittent and hard to integrate into the power grid. Sustainable electricity production is dependent on the weather, under- and oversupplies occur and destabilize the grid.

Virtual power plants (VPP) play an important role in stabilizing the grid. VPPs aggregate distributed power sources to consume and produce electricity when it is needed. Carsharing companies operate large, centrally-managed fleets of electric vehicles (EV) in major cities around the world. These EV fleets can be turned into VPPs, using their batteries as combined electricity storage. In this way EV fleets can offer balancing services to the power grid or trade electricity on the open markets for arbitrage purposes.

Carsharing companies can charge the fleet (buy electricity), when there is an excess of electricity and discharge EVs (sell electricity), when there is a shortage of electricity. By making their EVs available to be used as a VPP, carsharing companies compromise customer mobility and the profitability of their fleet. Renting out an EV to a customer is considerably more lucrative than using it for trading electricity.

Knowing how many EVs will most likely be rented out in a future point of time and consequently obtaining an accurate forecast of available battery capacity is essential for a successful trading strategy. Moreover it is possible for fleet owners to trade on multiple electricity markets simultaneously. Electricity markets differ in price elasticity, as well as reaction time between contractual agreement and physical delivery.

Participating in operating reserve markets and spot markets at the same time can mitigates risks and increase profits. Allocating EVs to different types of VPPs, that participate on the respective markets is an optimization problem, which we aim to solve.

In this research we propose a portfolio optimizing strategy, in which the best composition of the VPP portfolio, consisting of operating reserve VPPs and spot market VPPs, will be dynamically determined. To address changing electricity price levels and customer demands over time we additionally propose an the use of intelligent agent trading strategy, in which an agent learns from historical data and adjust to its current environment.

The following tasks will be performed by the agent in real time: 1) *Allocation of plugged in EVs to idle or VPP state*, 2) *Learn the optimum of VPP portfolio composition* and 3) *Place bids and asks on corresponding electricity markets with an integrated trading strategy.*

1.2 Research Question

Drawing upon the research motivation, the following research questions are derived. They build upon another and will be sequentially addressed during this research:

1. *What are spatio-temporal customer demand patterns of carsharing EVs?*

   Knowing customer demand patterns results in an accurate forecast of how much available battery capacity an EV fleet will have at any point in time.

2. *What is the optimal allocation ratio of the available capacity between operating reserve market VPPs and spot market VPPs?*

   Dynamically learning the optimal share of capacity to trade on the respective markets will maximize profits, while reducing the risk of foregone customer profits.

3. *How does an integrated bidding strategy look like, which considers trading electricity the secondary operating reserve market and the continuous intraday market simultaneously?*

   Designing a strategy and determine optimal auction prices, which takes the specific market designs of the German secondary operating reserve market and continuous intraday market into account.

2 Relevance of the Research

2.1 Relevance to Practice

From a business perspective this research is mainly relevant to carsharing companies, such as Car2Go or DriveNow, which are operating an EV fleet. We will show how these companies can increase their profits, using idle EVs as VPPs to trade electricity on multiple markets simultaneously.

We propose the use of a decision support system (DSS), which allocates idle EVs to either type of VPP or to be available for renting. Furthermore the DSS will determine optimal ask, bids and capacities to trade on the individual electricity markets.

In addition, we will estimate the profitability increase, when implementing the proposed methods. This will be done using real-world data from German electricity markets and trip data from a German carsharing provider.

2.2 Relevance to Science

From a scientific perspective this research is relevant to the stream of agent-based decision making in smart markets (Bichler, Gupta, & Ketter, 2010; M. Peters, Ketter, Saar-Tsechansky, & Collins, 2013). We will contribute to the body of Design Science in Information Systems (Hevner, March, Park, & Ram, 2004) and draw upon work done in multitude of research areas: Virtual Power Plants in smart electricity markets (Pudjianto, Ramsay, & Strbac, 2007), carsharing as a new way of sustainable mobility and advanced machine learning methods for forecasting and prediction.

Similar research has been carried out by Kahlen, Ketter, and van Dalen (2018) and Kahlen, Ketter, and Gupta (2017). In their research the authors concentrate on participating in one type of electricity market at a time. As proposed by Kahlen et al. we will take this research further and use the EV VPPs to act on multiple types of electricity markets simultaneously. Moreover we aim to use sophisticated machine learning methods (i.e. recurrent neural networks, ensemble learning) to carry out more accurate forecasts of rental demand and dynamically learn allocation ratios to the individual markets.

He, Chen, Kang, Pinson, and Xia (2016) and Mashhour and Moghaddas-Tafreshi (2011a, 2011b) researched on optimal bidding strategies for using VPPs to jointly bid on multiple markets. The authors use stationary storage to participate in day-ahead and spinning-reserve markets. Contrarily, we aim to use non-stationary storage (i.e. EV batteries) to participate in the continuous intraday market and the secondary reserve market (known as real-time market in the US).

2.3 Relevance to Society

This research contributes to the overall welfare of the society in three points. First, VPPs of EVs provide extra balancing services to the power grid. The VPPs can consume excess electricity (almost) instantly and stabilize the power grid like this. When integrating more intermittent renewable electricity sources into the grid in the future, such balancing services will become indispensable.

Second, a reduction of electricity prices for the end-consumer is expected. Integrating VPPs into the power grid increases the efficiency of the whole system and hence is lowering prices. Kahlen et al. (2018) show results, where electricity prices decrease up to 3.4% on the wholesale market. We anticipate similar results in our research.

Third, VPPs can lead to a decrease in CO_2 emissions. With an increasing share of renewable energy production, the supply of sustainable electricity can excess total electricity demand at times of good weather conditions. The VPPs can consume this electricity by charging the EV fleet and the sustainable energy production does not need to be curtailed. The EV fleet can then feed the electricity back into the grid, when there is more demand than sustainable electricity production. With this mechanism the total CO_2 emissions can be reduced.

3 Empirical Setting

We chose to embed our research in the German carsharing and electricity market. Germany has a comparably high share of renewables in its energy mix and is pushing for a energy turnaround[1] (German: *Energiewende*) since 2010. The high renewable energy content in the energy mix causes electricity prices to be more volatile, which makes Germany an attractive location for the use of VPPs. We obtained real-world trip data from Daimlers carsharing service Car2Go[2] and electricity market data from European power exchange EPEX SPOT[3]. Additionally we collected data from the German electricity market operator regelleistung.net[4].

3.1 Carsharing Fleets of Electric Vehicles

We think that the future of mobility will be electric, shared, smart and eventually autonomous. Carsharing companies are already contributing to the first two points by operating large fleets of electric vehicles. This research addresses the third point:

[1] *Energy concept for an environmentally sound, reliable and affordable energy*, German Federal Ministry of Economics and Technology (BMWi), 2010.

[2] https://www.car2go.com

[3] https://www.epexspot

[4] https://www.regelleistungen.net

Using EV fleets to smartly participate on electricity markets, without compromising customer mobility. Carsharing providers like Daimler and BMW operate their carsharing fleets in a free-float model, where people can pick up and drop vehicles at any place withing the operating zone of the provider. Customers pay by the minute and are offered incentives to park EVs at charging stations. Analyzing free float trip data is substantially more difficult as trip data, which are bounded by fixed stations. Individual trips have to be reconstructed using the GPS data of the cars and predicting the rental demand is a complex matter. The demand differs depending at which place and at what time the EVs are parked. The dataset consists of 500 EVs in the German city Stuttgart. As displayed in Table 1 the data contain spatio-temporal attributes, such as timestamp, coordinates and address of the EVs. Additionally status attributes of the interior and exterior are given, the percentual state of charge and information whether the EV is plugged into one of the 200 charging stations in Stuttgart.

Table 1: Raw Car2Go Trip Data from Stuttgart

Number Plate	Latitude	Longitude	Street	Zip Code	Engine Type
S-GO2471	9.19121	48.68895	Parkplatz Flughafen	70692	electric
S-GO2471	9.15922	48.78848	Salzmannweg 3	70192	electric
S-GO2471	9.17496	48.74928	Felix-Dahn-Str.45	70597	electric
S-GO2471	9.17496	48.74928	Felix-Dahn-Str.45	70597	electric
S-GO2471	9.17496	48.74928	Felix-Dahn-Str.45	70597	electric
Number Plate	**Interior**	**Exterior**	**Timestamp**	**Charging**	**State of Charge**
S-GO2471	good	good	22.12.2017 20:10	no	94
S-GO2471	good	good	24.12.2017 23:05	no	72
S-GO2471	good	good	26.12.2017 00:40	yes	81
S-GO2471	good	good	26.12.2017 00:45	yes	83
S-GO2471	good	good	26.12.2017 00:50	yes	84

3.2 Electricity Markets

On electricity markets actors participate in auctions to match supply of electricity generation and demand of electricity consumption. Participants place asks (sale offers) and bids (purchase orders). The price is determined by an auction mechanism, which can take different forms, depending on the type of market. Germany, as many other countries, has an liberalized energy system in which the generation and distribution of electricity is decoupled. Multiple electricity markets exists, which differ in their reaction time between the order contract and the delivery of electricity. Day-ahead and spot markets have a reaction time between a day and several hours, whereas in operating reserve markets the reaction time ranges from minutes to seconds.

The auction mechanism design is essential for electric markets (Kambil & van Heck, 1998). Electricity markets work according to the merit order principle. Resources are considered in an ascending order of the energy price until the capacity demand is met. The clearing price is determined by the energy price, at the point where supply meets demand. Payment models differ in the markets: In contrast to day-ahead market, where a uniform pricing schema is applied, in secondary reserve markets and intraday markets bidders get compensated by the price they bid for (pay-as-bid principle).

Carsharing Fleets can offer the capacity of their EV batteries on multiple markets at the same time to make use of the different market properties. On operating reserve markets prices are usually more volatile and consequently more attractive for VPPs. But they also bear a higher risk for the fleet. Commitments have to be made one week in advance, where customer demands are still of uncertain. To not face penalties for unfulfilled commitments only a conservative amount of capacity can be offered to the market. Spot markets allow participants to continuously trade electricity products up to fifteen minutes prior to delivery. At this point it is possible to predict if a EV is likely going to be rented out with a high accuracy. This creates the possibility to trade the remaining available capacity with a low risk at the spot market.

3.2.1 Secondary Operating Reserve Market

In this research we will use bidding data from the German secondary reserve market between 01.06.2016 and 01.01.2018. The data contain weekly lists of anonymized bids, where the electricity product, the offered capacity, the capacity price and the energy price of the placed bids are listed. As also negative prices are allowed, the payment direction is included as well. Moreover we find information about which amount of electricity accepted, i.e. either partially or fully. Bids which weren't accepted are not listed. An excerpt of the data can be found in Table 2.

Table 2: List of Bids of the German Secondary Reserve Market

Product[5]	Capacity Price[6]	Energy Price[7]	Payment	Offered[8]	Accepted[8]
NEG-HT	0	1.1	TSO to bidder	5	5
NEG-HT	0	251	TSO to bidder	15	15
NEG-HT	0	564	TSO to bidder	22	22
...	...	...	...	...	...
NEG-NT	0	21.9	Bidder to TSO	5	5
NEG-NT	0	22.4	Bidder to TSO	5	5
...	...	...	...	...	...
POS-NT	696.6	1200	TSO to bidder	5	5
POS-NT	717.12	1210	TSO to bidder	10	7

3.2.2 Continuous Intraday Spot Market

We will embed this research in the EPEX Spot Intraday Continuous market. The data has been provided by ProCom[13] and encompasses data of order books and executed trades from 01.06.2016 till 01.01.2018. As displayed in Table 3 trades can have a very short lead time before delivery. Electricity products are: 30-minute contracts, hourly contracts and block contracts can be traded. Participants can submit limit orders at any time during the trading window and equally change or withdraw the order at any time before the order is accepted. Limit orders are specified as quantity/price pairs. When an order to buy (bids) and an order to sell (asks) is matched the trade will get executed. The order book is visible to all participants, hence it is known which unmatched orders exists at the time of interest.

[5]NEG-NT = Product code for negative secondary control reserve to be provided between the hours of 00:00h and 08:00h as well as between 20:00h and 24:00h from Monday through Friday as well as all day on Saturday, Sunday and public holidays applicable to all of Germany. POS-HT = Product code for positive secondary control reserve to be provided between the hours of 08:00h and 20:00h from Monday through Friday.

[6]Capacity prices are in given in €/MW.

[7]Energy prices are in given in €/MWh.

[8]Capacities are given in MW.

[13]https://procom-energy.de/

[10]Unit prices are given in €c/MWh.

[11]Quantities are given in kW.

Table 3: List of Trades of the EPEX Spot Intraday Continous Market

Exec time	ID	Unit price[14]	Quantity[15]	Buyer area	Seller area	Delivery date	Product	Product time
2017-12-04 06:54:55	8031392	5100	5500	Amprion	Amprion	2017-12-04	H	08-09
2017-12-04 06:53:26	8031391	5900	10000	TenneT	TenneT	2017-12-04	H	08-09
2017-12-04 06:53:26	8031390	5890	10000	TenneT	TenneT	2017-12-04	H	08-09
2017-12-04 06:53:15	8031389	5230	7000	50Hertz	50Hertz	2017-12-04	H	08-09
2017-12-04 06:53:13	8031386	5900	500	TenneT	TenneT	2017-12-04	H	08-09
2017-12-04 06:53:13	8031387	5100	3600	Amprion	Amprion	2017-12-04	H	08-09
2017-12-04 06:53:13	8031388	5200	1400	Amprion	Amprion	2017-12-04	H	08-09
2017-12-04 06:53:02	8031385	5890	11000	TenneT	TenneT	2017-12-04	H	08-09
2017-12-04 06:52:38	8031380	6000	10000	Amprion	Amprion	2017-12-04	H	08-09
2017-12-04 06:52:38	8031381	5750	8000	Amprion	Amprion	2017-12-04	H	08-09
2017-12-04 06:52:38	8031382	5800	2000	Amprion	Amprion	2017-12-04	H	08-09
2017-12-04 06:52:38	8031383	5890	4000	TenneT	TenneT	2017-12-04	H	08-09
2017-12-04 06:52:38	8031384	6000	4000	Amprion	Amprion	2017-12-04	H	08-09
2017-12-04 06:52:27	8031379	5230	8000	50Hertz	50Hertz	2017-12-04	H	08-09
2017-12-04 06:51:33	8031378	6600	5000	TransnetBW	TransnetBW	2017-12-04	H	08-09
2017-12-04 06:51:28	8031377	5400	8000	Amprion	Amprion	2017-12-04	H	08-09
2017-12-04 06:51:24	8031376	5400	7000	TenneT	TenneT	2017-12-04	H	08-09
2017-12-04 06:49:34	8031375	5100	4000	TenneT	TenneT	2017-12-04	H	08-09
2017-12-04 06:49:26	8031374	5400	5000	50Hertz	50Hertz	2017-12-04	H	08-09
2017-12-04 06:49:23	8031373	5510	8000	50Hertz	50Hertz	2017-12-04	H	08-09

4 Literature Review (1-2 Pages)

- IS can help with climate change
- Use IS to align organizational goals with sustainability (carsharing and CO_2 emission) with DSS (Doing good by doing well)
- Use EV Fleets to align mobility goals with battery storage goals
- Demonstrate this with intelligent agent in an simulation similar to PowerTAC

4.1 Smart Charging

- Charging EVs at the same time can cause issues in the Grid. Overload transformers and substation (Kim, Tabors, Stoddard, & Allmendinger, 2012; Sioshansi, 2012)
- Solution in prev. literature: Smart charging: Charge when the list is less congested, reduce peak demands
- EV fleets are given financial incentive, because the price is lower(?) (Valogianni, Ketter, Collins, & Zhdanov, 2014)
- (Kara et al., 2015) Smart scheduling would result in even lower electricity costs for consumers
- Emphasize need for research on charging from the grid.
- (Fridgen, Mette, & Thimmel, 2014)

4.2 Vehicle-to-Grid

- Extension of the Smart Charging concept
- Shown succesfully with stationary storage (Mashhour & Moghaddas-Tafreshi, 2011b)
- (He et al., 2016) Battery life cycles, important.
- Also included in this study.
- V2G profitable (Peterson, Whitacre, & Apt, 2010; Reichert, 2010), but battery costs crucial

4.3 Dynamic pricing using batteries

- (Vytelingum, Voice, Ramchurn, Rogers, & Jennings, 2011) show that dynamic pricing for household is profitable
- Dynamic pricing in industries also profitable (Zhou, Scheller-Wolf, Secomandi, & Smith, 2015)
-

4.4 General EV profitability when used as Grid Storage

- (Schill, 2011) find EVS are profitable for consumer electricity prices when used as Storage (V2G)
- (Tomić & Kempton, 2007) V2G profitable, especially when high variablity in electricity prices
  - Shorter interval between sale and delivery, the larger the benefits

4.5 Electricity Brokers

- Studies have assumption that car owners or household can trade on wholesale markets, not realistic due to minimum capacity requirements
- Electricity Brokers (Ketter, Collins, & Reddy, 2013) introduced to act on behalf of a group
- (Brandt, Wagner, & Neumann, 2017) and (Kahlen, Ketter, & van Dalen, 2014)

4.6 VPP

- (Mak, Rong, & Shen, 2013)

4.7 Carsharing

- (Firnkorn & Müller, 2015) Freefloat carsharing reduce carbon emissions
- Wagner, Brandt, and Neumann, 2016
- Previous studies were trips known in advance: deterministic, free-float add uncertainty, per-minute

- EV either committed to be charged or discharged or free for renting. In reality trips are more spontaneous
- Offering EV capacity for control reserves not shown in business setting
- Other than (Kahlen et al., 2017; Kahlen et al., 2018) this has not been done yet.
- Kahlen present very conversative results and propose the combination of multiple markets in future work. In their approach the VPPs are mainly used to buy from the markets when electricity is cheap and thus charge their EVs basically for free (Citatation). V2G is almost never used.
- We will build on Kahlen results and introduce an integrated bidding strategy. We will draw on previous results from

He et al., 2016; Mashhour and Moghaddas-Tafreshi, 2011b and act on multiple markets.

4.8 Electricity Forecasting

Avci, Ketter, and van Heck, 2018

4.9 More Papers

4.9.1 Main Papers

4.9.2 Touching Papers and Conference Papers

Ketter et al., 2013

W. K. M. Peters, Collins, and Gupta, 2016

Ketter, Peters, Collins, and Gupta, 2016

Ketter et al., 2016

5 Research Design (1-2 Pages)

The research will be structured using the IS design science principles proposed Hevner et al. al. (2004). In Figure 1 the proposed research design is depicted. We will place a special focus on the used methodologies, the developed artifact and the evaluation of the results. Drawing from the *Knowledge Base*, multiple methods will be compared and evaluated against each other and thus emphasising *Research Rigor*. Considering *Business Needs*, we will develop an *Artifact* in form of a decision support system. Evaluating the results with real-world data with a simulation will make sure the *Artifact* is *applicable in the appropriate environment* (i.e. carsharing fleets).

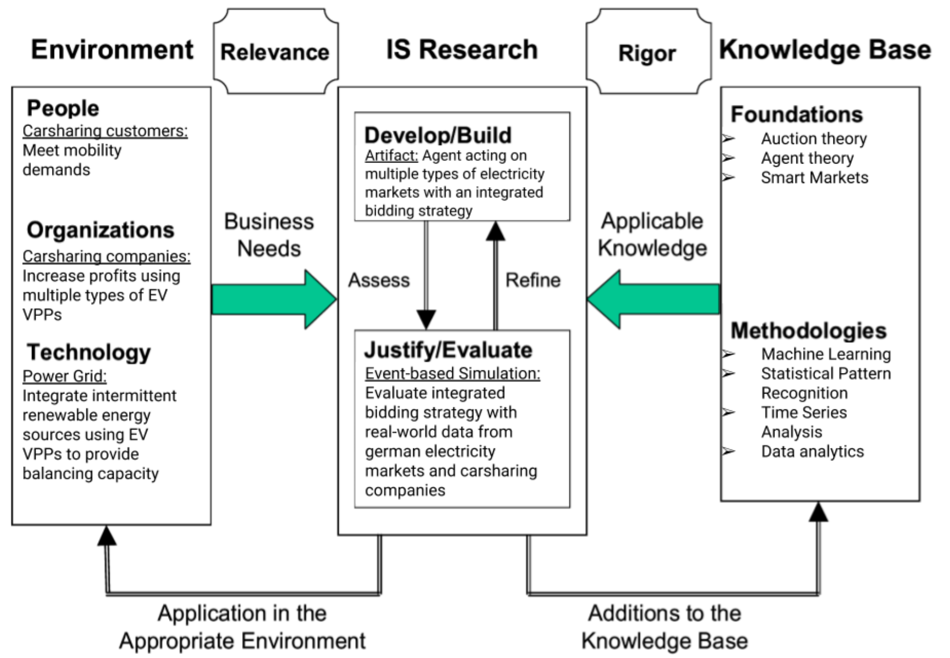

Figure 1: Research Design following Hevner et al., 2004

5.1 Problem relevance: Environmental (People), carsharing (Business)

5.2 Methodologies

Draw upon well researched statistical and machine learning methods: statistical pattern recognition, time-series forecasting and artificial neural networks.

5.2.1 Quantitative Study

- What is the purpose of the study?

  1. EV Capacity Prediction / Demand Prediction

2. Dynamic VPP Allocation Learning
3. Determine Bids/Asks/Market: Price Prediction

5.2.2 ML-based Intelligent Agents

5.3 Artifact: Instantiation of an intelligent agent.

- Thus: An intelligent Agent is needed, which dynamically allocates parked, plugged-in EVs to be used as VPP or stay idle, depending whether an EV is likely going to be rented out and how much capacity it has available.

5.4 Evaluation: Event-based simulation using real-world data

-Using real-world data from German electricity markets and trip data from a car-sharing provider.

6 Research Plan (0.5 Page)

7 Wolf Requirements

7.1 MA Proposal

- The proposal depicts the main background and motivation of your research topic.
- Based on the proposal, a concise research question is to be derived and formulated.
- The methodological approach shall be outlined.
- The suggested methods and algorithms shall be listed.
- Please give an overview on the respective data.
- The proposal already has to include relevant literature references.
- Please note that special focus shall be placed on the research question and the respective approach.

7.2 PhD Proposal

Specially attention is paid to related work, data, methods, and analysis, and potential contribution/conclusion.

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