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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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 (1 Page)

We chose to embed our research in the German 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.

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 06.06.2016 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 bid is listed. As also negative prices are allowed, the payment direction is included. Moreover we find information whether the bid was fully or partially accepted. That makes it easy to determine the clearing price.

3.2.2 Continuous Intraday Spot Market

3.2.3 German secondary operating reserve market

- Market design

[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.

Table 2: Anonymized List of Bids of the German Secondary Reserve Market (04.12.2017)

Product[5]	Capacity Price [EUR/MW]	Energy Price [EUR/MW]	Payment	Offered [MW]	Accepted [MW]
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

Table 3: Anonymized List of Bids of the German Secondary Reserve Market (04.12.2017)

Product[5]	Capacity Price [EUR/MW]	Energy Price [EUR/MW]	Payment	Offered [MW]	Accepted [MW]
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
...	...	...	...	...	...
POS-NT	717.12	1210	TSO to bidder	10	7

- Exemplary data 4

Table 4: Exemplary Spot Market Auction Data

Bid Id	Price
1	7
2	9
3	3

4 Literature Review (1-2 Pages)

4.1 Electric Vehicles, Virtual Power Plants, V2G

Peterson, Whitacre, and Apt (2010)

Mashhour and Moghaddas-Tafreshi, 2011a

Mashhour and Moghaddas-Tafreshi, 2011b

Mak, Rong, and Shen, 2013

Kim, Tabors, Stoddard, and Allmendinger, 2012

Kara et al., 2015

He et al., 2016

Fridgen, Mette, and Thimmel, 2014

Kahlen et al., 2018

- 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.

Kahlen et al., 2017

Kahlen and Ketter, 2015

4.2 DSS, Intelligent Agents, State of the Art ML Techniques

Avci, Ketter, and van Heck, 2018

4.3 Carsharing (?)

Firnkorn and Müller, 2015

4.4 More Papers

4.4.1 Main Papers

Sioshansi, 2012

Valogianni, Ketter, Collins, and Zhdanov, 2014

Vytelingum, Voice, Ramchurn, Rogers, and Jennings, 2011

Wagner, Brandt, and Neumann, 2016

Wolfson, Tavor, Mark, Schermann, and Krcmar, 2011

Zhou, Scheller-Wolf, Secomandi, and Smith, 2016

4.4.2 Touching Papers and Conference Papers

Ketter, Collins, and Reddy, 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 by Hevner et 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).

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.

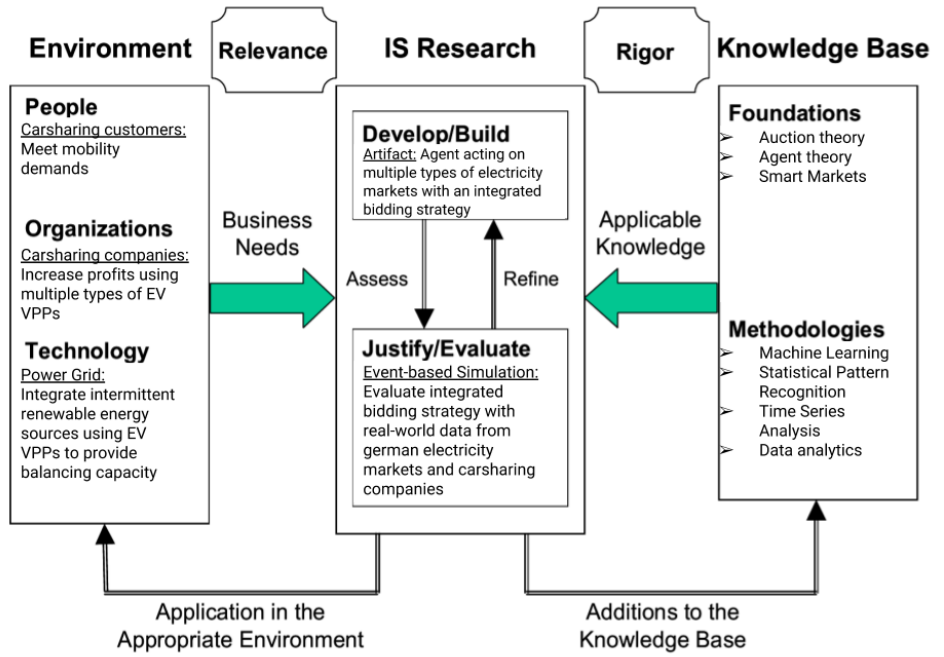

Figure 1: Research Design following Hevner et al., 2004

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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