Master Thesis Presentation

Assessing the Monetary Value of Vehicle-to-Grid Considering Battery Degradation: Agent-based approach

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1. Introduction
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2. Methodology

3. Results

4. Conclusions and Future Work
Growth of variable renewable energy (VRE) in the energy system and need for flexibility in the upcoming decade in the Netherlands

- Grid upgrades and storage capacities increase the overall system cost

- Rise in electric vehicle (EV) adoption with the dramatically fall in the battery prices - EVs expected to achieve price parity with ICE vehicles in 2022 [1]

- Intelligently integrating EVs and electricity system can provide synergetic benefits to both, known as **Vehicle-to-Grid (V2G)**

![Fig. 1: Installed capacities (left) and hours of utilisation (right) in the operation of different optimised energy storage technologies for Europe, 2000-2100. Reprinted from [2]]
V2G Service Provision to Energy System

Value

- Smoothing out price differentials / Time of Use / Energy arbitrage
- Market balancing / imbalance
- Frequency regulation
- Network congestion / peak avoidance
- Network quality (e.g. voltage)

Beneficiary

- Third Party Intermediary
- Transmission System Operator
- Distribution System Operator

Market

- Spot market
- Imbalance market
Previous V2G studies mainly focused on system benefits of the V2G

Benefits for different types of EV users is narrowly researched

Lacking socio-technical approach: user behaviour and characteristics, exogenous and endogenous factors

**The Netherlands**

- Monetary benefits for EV users in the Netherlands studied focusing on secondary reserve market (Imbalance market) only
- Limitations of Imbalance market: limited capacity and reduction of profitability due to market saturation
I. What is the monetary value created for different types of electric vehicle users who provide energy storage (V2G energy arbitrage) under Spot-market in the Netherlands?
   - Which are the factors affecting the V2G benefits?
   - How do these factors affect the benefits?

II. How V2G energy arbitrage influence the Spot-market electricity demand and prices collectively compare to other electric vehicle charging strategies in the Netherlands?
Fig. 2: Overview of SparkCity model Adapted from [3]
Agent-based modelling

- Transition of energy system from technical system to **complex socio-technical system**

- Complex interactions between different entities and collective influence of its on the system as a whole

- Suitability of Agent-based modelling to model such system:
  - Bottom-up approach
  - Autonomous, adaptive and interacting agents
  - Capturability of emergence

**Fig. 3**: Illustration of complex system
Agent-based modelling

- Three key elements of an agent-based model:
  - set of agents, attributes and their behaviour
  - agents relationships and interaction methods
  - environment

- Agents are software entities in the context of computer programming

- Flexibility of incorporating other modelling approaches

- Validation methods:
  - plausibility checks by domain experts or stakeholders
  - empirical validation of internal structure and behaviour
Modelling Approach

Agent-based modelling

Fig. 4: Structure of an agent-based model, adapted from [4]
1. Introduction

2. Methodology
   - System Description
   - Spot Market Module
   - Charging Scheduling Strategies
   - EV Charging Prices
   - Battery Degradation Costs
   - Modelling and simulation platform

3. Results

4. Conclusions and Future Work
Fig. 5: General structure of the model with key agents in the context of agent-based modelling.
Key agent type considered: Buildings, Adults, and Electric vehicles

Neighbourhood: ‘de Vliert’ from ’s-Hertogenbosch city in the Netherlands

Availability of EV Charging: at Workplace, Public location and Private (house)

Charging scheduling strategies:

- Uni-directional
  - Uncontrolled Charging Strategy (UCS) or Normal charging
  - Cost-based Charging Strategy (CBCS) or Smart charging

- Bi-directional
  - Vehicle-to-Grid Strategy (V2GS) or V2G
- Types of house: Apartments (117), Terraced houses (7), Detached houses (63), Corner houses (18)

- Private parking availability: Detached houses, Corner houses
Number of adults in the neighbourhood: 308
60% adults working in the neighbourhood
30% working adults have workplace EV charging capability
System Description

- **System Description**

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- **Attributes of an EV agent**
  - Connected adult agent
  - EV Driving behaviour
  - EV Charging behaviour
  - Charging scheduling strategies

- **EV battery size distribution**: 30-90 kWh
- **Numbers of EVs in the neighbourhood**: 205
- **Rated charging power**:
  - Workplace (11 kW)
  - Public (22 kW)
  - Private (7.4 kW) charge point

- **Change in spot-market prices based on added demand (for next EV)**

- **EV charging duration session** (t)
- **EV charging demand** (kWh)
- **Charging power** (kW)

- **Electricity consumption** (kWh)
- **Battery State of Charge** (%)

- **EV Charging location**
- **EV Charging connection probability** (%)

- **Charging session cost** (€)
- **Energy throughput** (kWh)
- **Average DoD**
- **Charge-discharge rate**
Fig 6: Merit-order with supply curve, demand curve, electricity price and their intersection

SRMC: Short Run Marginal Cost

Fig 7: Spot market hourly prices generation
Demand shift on spot market due to EV charging/discharging

\[ F_s = \frac{C_{nl}}{E_{sp}} \cdot E_a \]

\[ C_{avg}(t) = \frac{2 \cdot P_{avg}(t) + C_{cl}(t)}{3} \]

\[ D_s(t) = C_{avg}(t) \cdot \frac{F_s}{1000} \]

Where,

- \( F_s \): scaling factor used depending on the ratio between total cars in the Netherlands and total EVs in the neighbourhood
- \( E_{sp} \): Total numbers of EVs in the neighbourhood
- \( E_a \): EV adoption rate in the Netherlands
- \( C_{nl} \): Total numbers of cars in the Netherlands
- \( C_{avg}(t) \): Average charging load of an EV previously charged in time \( t \)
- \( C_{cl}(t) \): Charging load of an EV currently charging in time \( t \)
- \( D_s(t) \): Spot market demand shift in time \( t \)
- \( P_{avg}(t) \): Average charging load of an EV currently charging in time \( t \)
Charging Scheduling Strategies

**V2GS: Backward induction algorithm or shortest path problem**

\[ a^{opt} = \arg\max_{a_t \in \{c_p, 0, -c_p\}} U(a) \]

\[ U(a) = -\sum_{t=1}^{T} p_t(a_t) + V(x) \]

Subject to,
\[ x = b_{init} + \sum_{t=1}^{T} a_t \]
\[ b_{min} \leq x \leq b_{cap} \]
\[ x \geq b_{des} \]
\[ b_{min} = 0.1 \cdot b_{cap} \]

Where,
\[ a : \text{The vector which contains the chosen action for each time step} \]
\[ a_t : c_p \text{ (charging)} \quad a_t : -c_p \text{ (discharging)} \quad a_t : 0 \text{ (do nothing)} \]
\[ c_p : \text{Rated charging power for the connected EV} \]
\[ B : \text{Battery state of charge (state space)} \]
\[ b_{init} : \text{Initial value of battery state of charge in kWh} \]
\[ b_{min} : \text{Minimum allowed battery state of charge in kWh} \]
\[ p_t : \text{Spot market price at time step } t \]
\[ b_{cap} : \text{Electric vehicle battery capacity in kWh} \]
\[ T : \{1, 2, 3, \ldots, n\} \text{ (set of time-steps)} \]
\[ b_{des} : \text{Desired amount of battery level at the end of charging session in kWh} \]
\[ V(x) : \text{Function represent the battery state of charge at the end of charge session, where } x \in B \]
Charging Scheduling Strategies

V2GS: Backward induction algorithm or shortest path problem

Fig 8: Example of V2GS in the graph terminology
Cost based charging strategy (CBCS)

Fig 9: Example of CBCS scheduling strategy in the graph terminology
Uncontrolled charging strategy (UCS)

Fig 10: Example of UCS scheduling strategy in the graph terminology
EV Charging Prices

- EV charging prices composed of several components

- Currently V2G installations or activities considered from the consumer perspective

Taxation on V2G

- Proposed solution:
  - Net metering: electricity used for driving purpose and for flexibility provided

Fig 11: Composition of electricity prices for the EV charging as from the source [5] and discussion with expert in the Netherlands
Battery degradation cost is calculated based on battery energy throughput, average DoD, battery cycle life in numbers and battery prices in respective years.

- Residual value of the battery has been considered in the analysis.

- Comparison of scenario between life time battery cycles usage due to V2G and without V2G.

**Fig 12: Projected Battery prices and Battery cycles (100%DoD)**
AnyLogic

- Multi-method simulation modelling tool supports agent-based, discrete event and system dynamics simulation methodologies

- Graphical modelling language and possibility to extend simulation model with Java coding
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3. Results
   • Simulation Setup and EV Users Comparison
   • Influence on Spot Market Demand
   • Influence on Spot Market Prices
   • Charging Costs and Monetary Benefits
   • Net Monetary Benefits
   • Sensitivity Analysis of Charging Power (kW)

4. Conclusions and Future Work
Simulation setup

- Simulation are performed for three different years: 2019, 2025 and 2030
- Varying installed capacities of generators, EV penetration rate and hourly average demand in the Netherlands

Selected EV users for the comparison of monetary benefits

<table>
<thead>
<tr>
<th></th>
<th>User 1</th>
<th>User 2</th>
<th>User 3</th>
<th>User 4</th>
<th>User 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>EV Battery capacity (kWh)</td>
<td>90</td>
<td>75</td>
<td>60</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>Charge-point availability</td>
<td>Private &amp; Workplace</td>
<td>Private</td>
<td>Workplace</td>
<td>Public</td>
<td>Public</td>
</tr>
<tr>
<td>EV Charging power (kW)</td>
<td>7.4 &amp; 11</td>
<td>7.4</td>
<td>11</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Daily driving distance (km)</td>
<td>140-160</td>
<td>100-120</td>
<td>60-90</td>
<td>20-30</td>
<td>15-20</td>
</tr>
<tr>
<td>EV Plug-in duration (hours)</td>
<td>18-20</td>
<td>10-12</td>
<td>8-9</td>
<td>10-12</td>
<td>4-6</td>
</tr>
</tbody>
</table>

Table 1: Comparison of different EV users characteristics
Influence on Spot Market Demand

Fig 13: Hourly average demand shift due to charging of EVs on national compared with average demand of the Netherlands.
Influence on Spot Market Prices

Fig 14: Average market prices for UCS, CBCS, V2GS and the prices without the demand shift due to charging
Energy Costs and Monetary Benefits

Fig 15: Average market prices for UCS, CBCS, V2GS and the prices without the demand shift due to charging
### Charging Costs and Monetary Benefits

#### Fig 16: Comparison of charging costs based on different charging strategies and V2GS benefit w.r.t. UCS and CBCS

<table>
<thead>
<tr>
<th>Results</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2030</strong></td>
<td><strong>2025: 20% EVs, 51% Renewables penetration</strong></td>
</tr>
<tr>
<td><strong>2030 : 50% EVs, 65% Renewables penetration</strong></td>
<td></td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th></th>
<th>UCS charging cost</th>
<th>V2GS benefit w.r.t. UCS</th>
<th>V2GS benefit w.r.t. CBCS</th>
<th>V2GS energy cost</th>
<th>CBCS charging cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>User 1</td>
<td>€1,500</td>
<td>€500</td>
<td>€750</td>
<td>€1,000</td>
<td>€1,250</td>
</tr>
<tr>
<td>User 2</td>
<td>€1,100</td>
<td>€300</td>
<td>€550</td>
<td>€900</td>
<td>€1,150</td>
</tr>
<tr>
<td>User 3</td>
<td>€1,000</td>
<td>€200</td>
<td>€450</td>
<td>€800</td>
<td>€1,050</td>
</tr>
<tr>
<td>User 4</td>
<td>€600</td>
<td>€100</td>
<td>€350</td>
<td>€500</td>
<td>€650</td>
</tr>
<tr>
<td>User 5</td>
<td>€500</td>
<td>€50</td>
<td>€250</td>
<td>€400</td>
<td>€550</td>
</tr>
</tbody>
</table>
Net Monetary Benefits

2019: 2% EVs, 22% Renewable penetration

2025: 20% EVs, 51% Renewable penetration

2030: 50% EVs, 65% Renewable penetration

Fig 17: V2G benefit w.r.t. UCS & CBCS with varying charging power
Fig 18: V2G benefit w.r.t. UCS & CBCS with varying charging power
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Monetary benefits are comparably lower than other V2G services

In future, V2G in day-time or at work-place charge-point can provide higher benefits compared to overnight charging due to high solar energy production

V2G net benefits are increased with decrease in battery prices and increase in battery cycles numbers

Influence of individuals characteristics on monetary benefits are higher
Future Work

- Develop profit maximisation algorithm considering battery degradation cost

- Consumer acceptance for V2G can be researched and based on that agent behaviour can be modelled further
Thank you!


