Electric mobility in future energy systems. Car as power plant?

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Content

• Variability in future energy systems
• Electric mobility and responsive demand
• Are the goals of many actors involved the same?
• Why EVs can be compared to cold storage warehouses?
• What can we learn from looking at different price scenario’s?
• Car as Power Plant
Future energy systems

Old
schedule generation
to meet demand

New
schedule demand
to meet generation

e.g. electric mobility
Future energy systems

Old
schedule generation
to meet demand

New
schedule demand
to meet generation

DSM - e.g.
electric
mobility
Future energy systems

- From “scheduling the generation to meet demand” to “everything interacts with everything”
- Increased real-time balancing
- Introduction of aggregators
Variability vs. Flexibility

The impact of variable generation

Our approach

• The world in “layers”:
  • institutions: laws and regulations
  • actors (social networks)
  • physical networks
• Strong Complex Adaptive Systems perspective
  ▪ Socio-technical complexity
  ▪ Evolution / coevolution / dynamics
  ▪ Multi level / Multi actors / Multi criteria / Multi time scale
• Multidisciplinary teams
  • combinations of different methods/theories
    ▪ Mathematical modeling, optimization and control
    ▪ Socio-technical ABM of systems evolution and operation
    ▪ Gaming
    ▪ Network theory / topology ...
  • out of the box thinking, e.g. are theoretically expected situations achieved?: If not, then what?
  • Empiricism: How do the different countries operate?
Power sector complex socio-technical system
Demand side - Electric mobility

How can electric mobility contribute to a more sustainable transportation & electrical power system and on the same time align the interests of its relevant actors?

Energy usage households +/- 10 kWh
Standard Household Profile

![Graph showing the standard household profile](image)

- **P\text{\_house} (kW)**
- **Time**

TU Delft
Estimation of the expected energy usage of EVs

Data from Mobility Research Netherlands

Average: ~34 km
~ 90% < 100km

Ministry of Transport, Public Works and Water Management, “Mobiliteitsonderzoek Nederland (in Dutch)”
Available: www.mobiliteitsonderzoeknederland.nl
Charging scenario's and network load
Based on real life data
Network load: 100 houses and 50 EVs

Price control

Load Control

Imbalance Control

Separate EV demand profiles
Charging strategy based on predicted price
Negative price?

Conventional, wind and solar power and spot prices for the German system on June 16th 2013.
Demand side – cold storage

Old
schedule generation
to meet demand

New
schedule demand
to meet generation

e.g. with a cold storage warehouse
Matching renewable energy and demand response through price

System model:
- Cold store has PV generation on site
- PV production known in advance
- Pays price $C_{in}(t)$ for energy, receives $C_{out}(t)$
- Temperature upper bound $T_{max}$

**Goal:** Investigate relations between demand response strategy of a cold store and electricity prices & Evaluate different pricing regimes on optimal energy use
Physical model of cold store

Heat balance

\[ C_p \frac{dT_c}{dt} = Q_{in} - Q_{out} \]

Incoming heat

\[ Q_{in} = UA(T_a - T_c) \]

Outgoing heat

\[ Q_{out} = \eta P_c \]

Resulting equation for T dynamics

\[ C_p \frac{dT_c}{dt} = UA(T_a - T_c) - \eta P_c \]

Discretized in time

\[ T_c[k + 1] = (1 - a)T_c[k] + aT_a[k] - bP_c[k] \]
Optimization formulation

Objective function

$$\min_{P_{in}[k], P_{out}[k]} \sum_{k=1}^{N_k} C_{in}[k]P_{in}[k] - C_{out}[k]P_{out}[k]$$

constraints

$$T_c[k+1] = (1-a)T_c[k] + aT_a[k] - bP_c[k]$$

$$P_c[k] = P_{PV}[k] + P_{in}[k] - P_{out}[k]$$

$$P_{c,min}[k] \leq P_{PV}[k] + P_{in}[k] - P_{out}[k]$$

$$P_{c,max}[k] \geq P_{PV}[k] + P_{in}[k] - P_{out}[k]$$
Compare cold store with EV optimization problem

Optimization problem

\[
\min_{P_{in[k]}, P_{out[k]}} \sum_{k=1}^{N_k} C_{in[k]} P_{in[k]} - C_{out[k]} P_{out[k]}
\]

s.t.

\[
T_{min[k]} \leq T_c[k] \leq T_{max[k]}
\]

\[
P_{c,min[k]} \leq P_c[k] \leq P_{c,max[k]}
\]

\[
\min_{P_{i,t}} \sum_t \sum_i C_t P_{i,t}
\]

s.t.

\[
x_{min,i} \leq x_{i,t} \leq x_{max,i}
\]

\[
P_{min,i} \leq P_{i,t} \leq P_{max,i}
\]

State dynamics

\[
T_c[k + 1] = (1 - a)T_c[k] + aT_a[k] - bP_c[k]
\]

\[
P_c[k] = P_{PV}[k] + P_{in[k]} - P_{out[k]}
\]

\[
x_{i,t+1} = x_{i,t} + \eta_i P_{i,t} \Delta t - d_{i,t}
\]
Price scenarios

A: flat tariff

B: flat double tariff

C: day-night tariff

D: APX based real time tariff

E: APX based real time tariff, high solar penetration
• Optimal cooling trajectory depends strongly on tariff structure.

• Local use of PV energy depends on tariffs

• Most 'value' of control in case with high solar penetration.

• The effective use of demand response requires the right tariff structure

<table>
<thead>
<tr>
<th>Price case</th>
<th>Profit (EUR)</th>
<th>Cooling Energy Used (MWh)</th>
<th>Total Energy Withdrawn (MWh)</th>
<th>Total Fed In (MWh)</th>
<th>Energy Withdrawn (kW)</th>
<th>Maximum Power Fed In (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: flat tariff</td>
<td>8500</td>
<td>19.4</td>
<td>9.9</td>
<td>31.2</td>
<td>220</td>
<td>1780</td>
</tr>
<tr>
<td>B: flat tariff, feed-in penalty</td>
<td>5310</td>
<td>20.3</td>
<td>0</td>
<td>20.4</td>
<td>0</td>
<td>1780</td>
</tr>
<tr>
<td>C: day-night tariff</td>
<td>6220</td>
<td>19.7</td>
<td>5.1</td>
<td>26.2</td>
<td>220</td>
<td>1780</td>
</tr>
<tr>
<td>D: APX based real time</td>
<td>7960</td>
<td>20.7</td>
<td>18.9</td>
<td>38.9</td>
<td>2000</td>
<td>2000</td>
</tr>
<tr>
<td>E: APX based high solar</td>
<td>4960</td>
<td>22.5</td>
<td>0</td>
<td>18.2</td>
<td>0</td>
<td>1504</td>
</tr>
</tbody>
</table>
How to define effective use of the demand response?

<table>
<thead>
<tr>
<th>Technological design</th>
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<tbody>
<tr>
<td>Technological system: demarcation, components, relations, processes</td>
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</tbody>
</table>

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<tr>
<th>Institutional design</th>
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<tbody>
<tr>
<td>Arrangements between actors that regulate their relations: tasks, responsibilities, allocation of costs, benefits and risks</td>
</tr>
</tbody>
</table>

The design process

Process design
Who participates in the design process; what are the conditions, rules, roles, items, steps, etcetera
Electric cars – disadvantages

Fuel cell cars
converts the chem. energy of a fuel (hydrogen) directly to electricity
Hydrogen production technology

Production technologies

- Natural Gas
  - Steam reforming
- Coal
  - Gasification
- Biomass
  - Gasification
- Electricity
  - Electrolysis
- Sunlight
  - Photo-electrochemical

Energy source

H₂
Efficiency cars

PETROL VS HYDROGEN

Energy efficiency compared

**Gasoline car**
1. Oil extraction + transport: 95%
2. Crude oil to gasoline: 90%
3. Combustion engine: 35%
4. Standby/Idle: 85%
Overall energy efficiency Petrol: 25%

**Fuel cell car**
1. Gas extraction + transport: 95%
2. Gas to hydrogen (H₂): 80%
3. Storage + Compression: 85%
4. H₂ de-Compression: 90%
5. Fuel cell: 60%
6. Electric motor: 95%
Overall energy efficiency Hydrogen: 33%
Power plants and car power capacity

**POWERPLANTS**
Total installed capacity (2010)

5,000 GW

**CARS**
1 car = 50 kW
1,000 million cars (2010)

1,000 million x 50 kW = 50,000 GW (5% of time in operation)

**New cars**
1 new car = 100 kW
80 million new cars per year

80 million x 100 kW = 8,000 GW / per year

1 GW = 10,000 new cars
Transport and Electricity system – expected changes

<table>
<thead>
<tr>
<th>SYSTEM</th>
<th>TRANSPORT/ELECTRICITY</th>
<th>SYSTEM CHANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present</td>
<td>Transport- and electricity systems are separated</td>
<td></td>
</tr>
<tr>
<td>Electric cars with batteries</td>
<td>Transport system with electric cars consumes electricity and can store electricity</td>
<td>More Electricity</td>
</tr>
<tr>
<td>Fuel cell car as power plant to produce electricity</td>
<td>Transport system with fuel cell cars produces electricity and will replace power plants</td>
<td>More Gas</td>
</tr>
<tr>
<td>Fuel cell car as power plant to balance electricity demand and supply</td>
<td>Electricity will be produced by renewable energy sources; hydro, geothermal, biomass, wind, solar</td>
<td>Fully Renewable</td>
</tr>
<tr>
<td></td>
<td>Transport system with fuel cell cars consumes electricity and biogas converted in hydrogen, produces electricity when necessary to balance electricity demand and supply</td>
<td></td>
</tr>
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</table>
## Reasons to believe

| EFFICIENCY                      | • Fuel cell in the car has an efficiency of 60% to convert hydrogen into electricity  
|                                | • Hydrogen production from gas or electricity has an efficiency of about 70-80% |
| BETTER                         | • Car engines at present have an efficiency of 25-40%  
|                                | • Power system efficiency is below 40% |
| TIME                           | • Cars are in use for transportation less than 5% of the time  
|                                | • Over 90% of time, cars are parked at home, at work, in a car park, on the street |
| AVAILABLE                      | • Power plants are used between 5% and 90% of the time |
| CAPACITY                       | • Worldwide 1 billion cars on the road; with an average engine capacity of 50 kW this represents a power capacity of 50,000 GW |
| ABUNDANT                       | • 80 million cars were sold in 2011; with an average engine capacity of 100 kW this represents a power capacity of 8,000 GW  
|                                | • Worldwide the electricity production capacity of all power plants is about 5,000 GW |
How to organize such a system?

- A wide variety of new products, services and systems to come, but who will deliver this?

- The cars need to be integrated in the larger energy and transport system. These challenges are on all system levels: from individual cars, to car parks, houses, offices, neighbourhoods, cities and regions.
Exploring the emergence of the Car as Power Plant with a socio-technical TIP design perspective
Agent-Based Model (ABM) for TIP design

Infrastructure Interaction

Physical Network | Actor Network
---------------|---------------
Physical Network | Actor Network

agent —— tech. —— agent

ABM components

- Agents
- States
- Decision rules
- Actions
- Environment
- Time
Modeling of energy infrastructures: ABM and TIP

- help to reduce uncertainty for actors in the energy chain by developing tools that are needed for smart energy systems