Electromobility Solutions for Cities and Regions
Life Cycle Assessment
Total Cost of Ownership

Kurt Hug
Bern University of Applied Sciences
Facts and Figures

Foundation: 1st October 1997
Departments:
- Architecture, Wood and Civil Engineering
- School of Agricultural, Forest and Food Sciences
- Bern University of the Arts
- Engineering and Information Technology
- Business, Health, Social Work
- Swiss Federal Institute of Sports Magglingen SFISM*

* affiliated college

Bachelor’s degree courses: 28
Master’s degree courses: 21
Teaching languages: German, French, partly English
Students: 6724
Proportion of women: 45 per cent
Staff: 2917 (1412 full-time equivalents)
Annual budget: CHF 265 Mio. (57 percent public sector grants)
EMLO$^S$ overall goal is to promote more sustainable transport through the development of electromobility solutions for cities and regions.
e-Mobility and e-Waste

Life Cycle Assessment

- Automotive Engineering
Agenda Part I: LCA

- Introduction
  - Issues in changing an energy carrier
  - The carbon cycle
- Life Cycle Assessment
  - Methods
  - LCA inventory data for the car production
  - Example: LCA of a Li-Ion battery
  - Environmental burden of Li-Ion-batteries
  - LCA inventory data for the provision of energy
- Conclusion: Environmental impact on whole CH-fleet
Issues in Changing an Energy Carrier

Lithium-economy instead of hydro carbon-economy

Black or Green?
Driving Concepts based on Hydro Carbons

Internal Combustion engine (ICE)

- Biogas (Methane) from
  - Biowaste (CH)
- Bioethanol (Alcohol) from:
  - Sugar cane (BR)
  - Wood waste (CH)
- Biodiesel (Methylester) from:
  - Palm oil (MY)
- Fossil Fuels
  - Natural gas
  - Gasoline
  - Diesel
The Carbon Cycle

Driving Concepts based on Lithium

Electric Drive with Battery (BEV)
- Nuclear CH (28 g/kWh)
- PV-mix (74 g/kWh)
- Avg. plug-mix CH (134 g/kWh)
- Electricity from modern combined cycle heat and power plant (444 g/kWh)
- Avg. plug-mix EU (UCTE, 593 g/kWh)
- Coal power plant (1095 g/kWh)

Hybrid (HEV)
- Gasoline

Plug-In Hybrid (PHEV)
- Avg. plug-mix CH (134 g/kWh)
- Gasoline
Life Cycle Assessment

Source: http://www.worldautosteel.org/life-cycle-thinking/
Methods

Future development of cars and components (literature review)
Future development of electricity market (officially, Swiss 2050)
Environmental impact (LCI database Ecoinvent)
Environmental impact of future cars (LCA)
Traffic forecasts CH (ABM)
Environmental impact on whole CH-fleet

Scenario «Business as usual»
Scenario «Efficiency»
Scenario «Networked mobility»
LCA Inventory Data Car Production Conversion Design

and for purpose design?
Life Cycle of a Li-Ion Battery
From Cradle to Cradle (C2C)

Ecoinvent Database

Input

Do While \{Li = VRM, Al = VRM, Cu, Fe\}
* No Cut-Offs

W2W
Li Battery Recycling (BATREC (under way))

Recycling today typically in CU-smelter

- Cu, Mn, Co, Ni, Fe are recycled
- Al, Li, Graphite and electrolyte are oxidised and lost in process
- Technologies to regain Al and Li will be feasible if more Li-batteries will be available for recycling
Environmental Burden due to the Battery

- Anode und cathode are important (50-80%)
- Cu foil of anode accounts for up to 43%; Al foil of cathode up to 20%
- Battery-pack (housing, electronics, wiring harnesses) not negligible (20-30%)
- Lithium-salts (in cathode and electrolyte) contribute relatively little (10-20%)

Environmental Burden of Li-Ion-Batteries

**BATTERY**

GHG-Emissions (%)

Environmental Impact (%)

**MOBILITY (driving 1 km)**

- **Battery Car**
  - Battery: 4
  - Anode: 16
  - Cathode: 14
  - LiMn: 14
  - Road: 8
  - Glider: 16
  - Drive-train: 7
  - Maintenance, disposal car: 14
  - Li-ion battery: 14
  - Operation: 4

- **ICE Car**
  - Battery: 4
  - Anode: 15
  - Cathode: 6
  - LiMn: 5
  - Road: 8
  - Glider: 16
  - Drive-train: 7
  - Maintenance, disposal car: 14
  - Li-ion battery: 14
  - Operation: 4

**GHG-Emissions (CO2-eq.)**

EU: 60

**Environmental Impact (EI 99 H/A)**

EU: 119

EU: 42

EU: 111
LCA Inventory Data for the Provision of Energy I

Source: Energieperspektiven 2050 (Stand Nov.12) , Auswertung Empa
LCA Inventory Data for the Provision of Energy II

- **Source:** Energieperspektiven 2050 (Stand Nov.12), Auswertung Empa; IPCC: Intergovernmental Panel on Climate Change

### Greenhouse gas emission, electricity supply CH

- **New gas fired power plants:** ca. 100 g CO$_2$eq/kWh
- **New renewable energies:** ca. 63 g CO$_2$eq/kWh
- **Combined heat power:** 21 kg CO$_2$-eq./kWh (IPCC)

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Source: Energieperspektiven 2050 (Stand Nov.12), Auswertung Empa; IPCC: Intergovernmental Panel on Climate Change
Technology-Development: Key Factors

BEV
- Battery price
- Energy density of battery
- Heating, air-conditioning

ICE
- Drivetrain efficiency

BEV & ICE
- Lightweight construction

> 30% Enhancement in efficiency by 2035
Greenhouse Gas Emission

Greenhouse gas emissions, „Compact“ (kg CO₂-eq/km)

- **ICE**
- **PHEV**
- **BEV**

**2012**
- ICE: 80%
- PHEV: <10%

**2020**
- ICE: 80%
- PHEV: <10%
- BEV: 23 kg CO₂-eq/km

**2035**
- ICE: 80%
- PHEV: <10%
- BEV: 23 kg CO₂-eq/km

**2050**
- ICE: 80%
- PHEV: <10%
- BEV: 23 kg CO₂-eq/km

Legend:
- Strasse
- Fahrzeug o. Batterie
- Batterie
- Strommix CH (BFE Szenario)
- Herstellung Treibstoff ICE
- Emissionen im Betrieb
Greenhouse Gas Emission

Greenhouse gas emissions, „Compact“ (kg CO$_2$-eq/km)

- **2012**
  - ICE
  - PHEV
  - BEV

- **2020**
  - ICE
  - PHEV
  - BEV

- **2035**
  - ICE
  - PHEV
  - BEV

- **2050**
  - ICE
  - PHEV
  - BEV

Legend:
- Strasse
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- Herstellung Treibstoff ICE
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Greenhouse Gas Emission

Greenhouse gas emissions, „Compact“ (kg CO₂-eq/km)

- CH, 30g CO2eq/kWh
- CH, 100g CO2eq/kWh
- EU, 420gCO2eq/kWh
- Global, 560gCO2eq/kWh

Berner Fachhochschule | Haute école spécialisée bernoise | Bern University of Applied Sciences
e-Mobility and e-Value

Total Cost of Ownership (TCO)
Agenda Part II: TCO

- Introduction
  - Cost drivers
  - Example gasoline driven car
- Particular aspects
  - Comparison BVE vs. ICE
  - Purchase prices
  - Residual value
  - Fuel costs
  - Service & repairs
  - Depreciation & amortisation
- Conclusion
TCO: Cost Drivers

**Financing**
- Purchase price
- Financing
- Depreciation
- Selling price

**Taxes & insurances**
- Taxes
- Charges
- Insurances
- Subsidies

**Operation**
- Fuel
- Maintenance
- Services
- Repairs
Example*: Gasoline driven Car with ICE

Total annual cost for our test vehicle
New price CHF 35’000, driving performance 15’000 km/year, useful life 8.7 years (annual costs = CHF 11’027)

**annual AMORTISATION**
(average 10% of new price)

due to effective driving performance
2% (new price) / 10’000 km

*TCS = Touring Club der Schweiz (analog ADAC, ÖAMTC)
Comparison BEV vs. ICE

Electric power train has wide-ranging influence on TCO

- Amortisation: 31.7%
- Garagierungskosten: 13.6%
- Versicherungen: 8.7%
- Reifenkosten: 6.2%
- Service und Reparaturen: 6.3%
- Wertminderung: 9.5%
- Treibstoffkosten: 15.1%

Fixe Kosten 60.2%
Variable Kosten 39.8%
## Purchase Prices

30% higher than a comparable petrol driven car

<table>
<thead>
<tr>
<th>Prices in CHF</th>
<th>BMW i3</th>
<th>Ford Focus Electric</th>
<th>Mitsubishi iMiEV 1)</th>
<th>Nissan Leaf</th>
<th>Renault Kangoo ZE</th>
<th>Renault ZOE</th>
<th>SMART ed</th>
<th>Tesla Model S</th>
<th>VW e-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Price</td>
<td>39'950</td>
<td>55'550</td>
<td>45'990 26'999</td>
<td>49'950 27'990</td>
<td>26'300</td>
<td>22'800</td>
<td>29'900</td>
<td>83'000</td>
<td>32'700</td>
</tr>
<tr>
<td>Electrical 2)</td>
<td>2'580</td>
<td>3'080</td>
<td>2'700</td>
<td>3'000</td>
<td>3'100</td>
<td>2'920</td>
<td>3'020</td>
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<td>2'340</td>
</tr>
<tr>
<td>Gasoline 3)</td>
<td>7'990</td>
<td></td>
<td></td>
<td>10'030</td>
<td></td>
<td>7'140</td>
<td></td>
<td>7'650</td>
<td></td>
</tr>
</tbody>
</table>

1) [http://www.mitsubishi-motors.ch/Switzerland/iframe/PCCIFrame/Car-Configurator-German/](http://www.mitsubishi-motors.ch/Switzerland/iframe/PCCIFrame/Car-Configurator-German/)


und Hersteller
Hedonic Methods for Residual Value of used Cars

\[ \ln(SP) = \alpha + \beta_1 \cdot \text{age} + \beta_2 \cdot \text{kil} + \beta_3 \cdot \ln(NP) + \gamma_1 \cdot D_{brand} + \ldots + \gamma_{15} \cdot D_{15\ brand} + \delta \cdot D_{time} + \varepsilon \]

The variables are explained in the following table.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(SP)</td>
<td>Sale Price</td>
</tr>
<tr>
<td>(NP)</td>
<td>Deflated original price of the new car</td>
</tr>
<tr>
<td>(age)</td>
<td>Age of car in months</td>
</tr>
<tr>
<td>(kil)</td>
<td>Relative mileage (kilometres travelled per month of age)</td>
</tr>
<tr>
<td>(D_{brand})</td>
<td>15 dummy brand variables (Audi, BMW, MB, VW, etc.)</td>
</tr>
<tr>
<td>(D_{time})</td>
<td>Time dummy variable</td>
</tr>
<tr>
<td>(\alpha)</td>
<td>Absolute term (based on 2003 values)</td>
</tr>
<tr>
<td>(\beta, \gamma, \delta)</td>
<td>Coefficient estimator (based on 2003 values)</td>
</tr>
<tr>
<td>(\varepsilon)</td>
<td>Random variable</td>
</tr>
</tbody>
</table>

Source: https://www.destatis.de/DE/Publikationen/WirtschaftStatistik/Preise/HedonpreisGebrauchtwagen.html
## Fuel Costs

70% lower than a comparable petrol driven car

<table>
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<td></td>
<td>7'650</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- 2.) Cost of electricity for 100’000 km
- 3.) Consumption figures according to OEMs, price of gasoline CHF 1.70/liter
- Plus additional reflections (home charge during low tariff, etc.)

Source: http://www.topten.ch/deutsch/mobilitat/elektro-auto/elektro.html und Hersteller
Fuel Costs CH 1985 - 2013 – Future?

Tendencies: fuel costs are raising, electricity costs are volatile

Costs unleaded petrol (CHF/liter)

- 10 years (2003 – 2013): 35%
- 20 years (1993 – 2013): 50%
- Peak oil?

Costs electricity (Cts/kWh), CH green: Households

- 10 years (2003 – 2013): 6%
- 20 years (1993 – 2013): 12%
- Influence of energy turnaround?
- Own electricity production (PV)?
# Service & Repairs

Guarantees (Internet OEM’s, April 2014)

<table>
<thead>
<tr>
<th></th>
<th>Guarantee for Vehicle</th>
<th>Guarantee for Battery</th>
<th>Service</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mitsubishi iMiev</strong></td>
<td>3 years / 100‘000 km</td>
<td>5 years / 100‘000 km</td>
<td>No indication</td>
</tr>
<tr>
<td><strong>Peugeot iOn</strong></td>
<td></td>
<td>5 years / 50‘000 km</td>
<td>No indication</td>
</tr>
<tr>
<td><strong>Nissan Leaf</strong></td>
<td>3 years / 100‘000 km</td>
<td>5 years / 100‘000 km</td>
<td>No indication</td>
</tr>
<tr>
<td><strong>Renault Zoe</strong></td>
<td>3 years / 100‘000 km</td>
<td>5 years / 100‘000 km</td>
<td>No indication</td>
</tr>
<tr>
<td><strong>VW e-up</strong></td>
<td>2 years / no Limit</td>
<td>8 years / 160‘000 km</td>
<td>No indication</td>
</tr>
<tr>
<td><strong>Tesla Model S</strong></td>
<td>4 years / 80‘000 km</td>
<td>8 years / 200‘000 km</td>
<td>CHF 1’850 for 4 years</td>
</tr>
</tbody>
</table>

**Electricity for free!!!!**

### Approximations: green BEV, green & black ICE

- **Service:**
  - Brake pads, break fluid, windshield washer fluid, shock absorber, car wash, timing belt, oil changes, spark plugs, cooling liquid, air filter

- **Repairs:**
  - Glass, coating, power steering, air condition, power windows, motor, exhaust system, gearbox
Depreciation & Amortisation I

Source: Achim Kampker · Dirk Vallée · Armin Schnettler, Elektromobilität, Grundlagen einer Zukunftstechnologie, ISBN 978-3-642-31985-3, Springer Verlag
Depreciation & Amortisation (many unknowns) II

Prices for electric and petrol driven used cars (autoscout24.ch)
Vehicles as identical as possible (what exactly does identical mean?)
Contradiction with forecasts, “EUROTAX” values not yet available

<table>
<thead>
<tr>
<th>Mitsubishi iMiev</th>
<th>HONDA Jazz 1.2l Trend</th>
<th>Smart Fortwo ed</th>
<th>Smart Fortwo passion</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHF</td>
<td>Residual value</td>
<td>CHF</td>
<td>Residual value</td>
</tr>
<tr>
<td>New prize</td>
<td>25’000</td>
<td>18’000</td>
<td>29’000</td>
</tr>
<tr>
<td>1 year/5’000 km</td>
<td>22’500</td>
<td>16’000</td>
<td>24’000</td>
</tr>
<tr>
<td>2 years/10’000 km</td>
<td>20’000</td>
<td>13’000</td>
<td>22’000</td>
</tr>
<tr>
<td>3 years/20’000 km</td>
<td>18’000</td>
<td></td>
<td>22’000</td>
</tr>
<tr>
<td>3 years/35’000 km</td>
<td>10’000</td>
<td></td>
<td>18’000</td>
</tr>
<tr>
<td>Bat. leasing/month</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Residual value of luxury cars after 3 years
- According to TCS: 35%
- Tesla leasing offer: 53% (still a business for TESLA?)

Sources: http://www.autoscout24.ch, April 2014
http://www.tcs.ch/de/assets/fahrzeugmarkt/wertentwicklung-personenwagen.pdf
Conclusion TCO Electric Vehicle

- Residual Values are difficult to estimate but decisive together with acquisition costs
- Country specific

+30% bis -30%
Danke für Ihre Aufmerksamkeit

Ebenfalls Danke für ihre Mithilfe an:

▶ Marcel Gauch, EMPA St. Gallen
▶ Peter de Haan, Ernst Basler + Partner
▶ Simon Pfister, Universität St. Gallen
▶ Matthias Botta, ELMOs

Kurt Hug
Q2 2013

Plug-in Electric Vehicles: Market Analysis and Used Price Forecast

Conversely, NADA expects that a combination of factors—particularly growing used vehicle supply and the shifting of consumer tastes back to new vehicles—will see ICE and HEV depreciation steadily worsen from 2012’s exceptionally strong figures to 16.8 and 18.5 percent, respectively, by 2014. Regardless, for the foreseeable future, it remains that the value proposition of a plug-in EV will be substantially worse than that of its two counterparts.

### USED VEHICLE DEPRECIATION: GASOLINE, HYBRID AND PLUG-IN ELECTRIC CARS

<table>
<thead>
<tr>
<th>Powertrain Type</th>
<th>Actual</th>
<th>Forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CY2012</td>
<td>CY2013</td>
</tr>
<tr>
<td>ICE</td>
<td>-12.4%</td>
<td>-13.3%</td>
</tr>
<tr>
<td>Hybrid</td>
<td>-14.0%</td>
<td>-16.9%</td>
</tr>
<tr>
<td>PEV</td>
<td>-31.5%</td>
<td>-29.7%</td>
</tr>
</tbody>
</table>

Source: NADA