Integration of electric vehicles (EV) into the future energy supply system

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Main research questions with the focus on Germany

Which assumptions and premises lead to a successful EV scenario and what could be the resulting fleet composition and electricity demand?

What could be an optimised integration of EV if we primarily aim for positive effects for the national energy system?

Different perspectives

► National/transnational perspective: central economic optimisation target “power generation system incl. transmission and storage”

► Regional perspective: avoid overload and expansion of distribution grids and transformers

► Local perspective households: minimize supply costs by increasing own consumption of decentralized power generation (PV, CHP)
**Models and basic methodology used**

**contribution of DLR in the frame of a research project funded by BMWi**

- **Fleet simulation**
  - market scenario,
  - electricity demand of the fleet *(VECTOR 21)*

- **Hourly user profiles**
  - basis: real world data

- **Vehicle simulation**
  - vehicle concepts, specific electricity demand & battery SOC temporally *(Dymola/Modelica)*

- **Simulation of electricity supply**
  - temporal and spatial resolution,
  - "optimised" annual supply,
  - Charging strategies, interaction Vehicles and power supply system *(REMix)*

- **Simulation of power transmission grid (HV)**
  - limitations, transfer capacities,
  - Need for expansion
  - *(UCTE-model of FGH, Aachen)*

**Techno-economic development paths up to 2050:**
- batteries, vehicle concepts, technologies and mix of electricity generation, power grids, oil price path, transportation demand, costs, consumption and performance of future cars etc.
Main explicit and implicit societal assumptions

- “Energiewende” in the power sector will be realised (>80% RE). Annual electricity consumption of EV is 100% RE (additionally installed capacities)

- Vehicle market: smaller vehicles, sales follow TCO, EV performance meets requirements of several consumer groups

- Central charging optimisation: business models and implementation of smart grids/controlling devices successful and accepted by the consumers

- Positive role of all relevant actors:
  - battery & car manufacturers: R&D, standardisation, develop. of value chains
  - electricity supplier: charging concepts, supply with RE power…
  - service providers: innovative, flexible, accessible
  - research & development: new materials and concepts
  - consumers: acceptance of new technologies/mobility, charging control…
  - government: CO₂ limits & penalties, R&D, incentives for market introduction
  - municipalities: public fleets & charging infrastructures, services…

Vehicle concepts & electricity demand of the future
results of simulations by system model Dymola/Modelica, real world driving profiles

- Battery capacities: BEV 22 – 62 kWh        EREV 16 – 24 kWh
- Electric ranges:  BEV 120 – 210 km        EREV 60 km
- Energy consumption: BEV 15 – 25 kWh/100 km EREV 15 – 24 kWh/100 km
- Energy density battery in Wh/kg: 2010: 120  2030: 230  2050: 250 / 400

Assumptions regarding grid connection

<table>
<thead>
<tr>
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<th>likelihood</th>
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<tbody>
<tr>
<td>at work</td>
<td>50%</td>
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<tr>
<td>education</td>
<td>40%</td>
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<td>business trip</td>
<td>10%</td>
</tr>
<tr>
<td>escort</td>
<td>10%</td>
</tr>
<tr>
<td>private</td>
<td>10%</td>
</tr>
<tr>
<td>shopping</td>
<td>30%</td>
</tr>
<tr>
<td>leisure activities</td>
<td>30%</td>
</tr>
<tr>
<td>others</td>
<td>10%</td>
</tr>
<tr>
<td>after last trip</td>
<td>70%</td>
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</tbody>
</table>

Moderate, current technologies! Scenario 1
Optimistic, new technologies! Scenario 2

BEV = battery electric vehicle      EREV = electric range extender vehicle
Operational profiles of individual electric cars
for each individual vehicle the minimal and maximal battery state of charge was calculated based on real world profiles (MiD 2008)

Binary operational profile (example)

- Driving (binary)
- Grid connection (binary)
- SOC (%)

possible SOC-profile controlled charging
start charging process as late as possible
security margin "x"

range for controlled charging

SOC\textsubscript{max} = uncontrolled charging
SOC\textsubscript{min} = battery empty after last trip

source: DLR-FK * SOC = state of charge
Operational profiles of the fleet: example „small BEV“
derived from all suitable profiles (MiD 2008) by overlapping the distribution functions of battery SOC for the complete „fleet“

$\text{SOC}_{\text{max}} = 20.5 \text{ kWh}$

$\text{SOC}(7\text{h}) = 13.8 \text{ kWh}$
($\approx 64\% \text{ bzw. 78 km}$)

$\Delta \text{SOC}(9\text{h}) = 3.1 \text{ kWh}$

$\text{SOC}(20\text{h}) = 12.6 \text{ kWh}$
($\approx 58\% \text{ bzw. 70km}$)

$\text{SOC}_{\text{min}} = 2.2 \text{ kWh}$
Market and fleet development

Simulation of technology development and consumer demand (model VECTOR21)

- Energy demand
- Technology costs
- Fuel prices, taxes, ...

Computer model:
- Efficiency packages
- Drive concept
- Fuel type
- Vehicle size
- Technical components
- Vehicle
- Choice
- Consumer (900 groups)
- "Adopter" type
- Annual mileage
- Willingness to pay

Sales/ market shares → CO₂ emissions

Source: DLR-FK
Fleet scenario calculated by VECTOR21: main assumptions influencing vehicle sales of different consumer groups (based on TCO*) for Scenario 2 „successful“

<table>
<thead>
<tr>
<th>assumptions</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil price [€/bbl]</td>
<td>60</td>
<td>80</td>
<td>130</td>
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<td>DLR analysis</td>
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<td>CNG tax [%]</td>
<td>20</td>
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<td>Current law</td>
</tr>
<tr>
<td>Electricity price [€ ct/kWh]</td>
<td>21,5</td>
<td>34,1</td>
<td>37,3</td>
<td>36,4</td>
<td>35,7</td>
<td>BMU study: for RE „Leitszenario 2010“</td>
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<tr>
<td>H₂ price [€ ct/kWh]</td>
<td>22,3</td>
<td>39,0</td>
<td>37,6</td>
<td>36,5</td>
<td>35,5</td>
<td>calculated</td>
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<tr>
<td>Share H₂ from electrolysis [%]</td>
<td></td>
<td>100%</td>
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<td>DLR analysis</td>
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<tr>
<td>CO₂ intensity electricity [g/kWh]</td>
<td>540</td>
<td>510</td>
<td>21 (as of 2025)</td>
<td></td>
<td></td>
<td>„Leitszenario 2010“, 100% RE as of 2025</td>
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<tr>
<td>CO₂ intensity H₂ [g/kWh]</td>
<td>648</td>
<td>612</td>
<td>25 (as of 2025)</td>
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<td>calculated</td>
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<td>CO₂ limit (EU level) [g CO₂/km]</td>
<td>2015: 130</td>
<td>118</td>
<td>97</td>
<td>80</td>
<td>70</td>
<td>Current law and BMU</td>
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<td>CO₂ penalties [€/ (g CO₂/km)]</td>
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<td>95</td>
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<td>Current law, DLR analysis</td>
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<tr>
<td>Willingness-to-pay [%]</td>
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<td></td>
<td></td>
<td>0-20</td>
<td></td>
<td>Rogers 1995, consumer analysis</td>
</tr>
<tr>
<td>Segments of new cars [S/M/L %]</td>
<td>(25/55/20)</td>
<td>(28/50/22)</td>
<td></td>
<td>(30/45/25)</td>
<td></td>
<td>KBA</td>
</tr>
</tbody>
</table>

source: DLR-FK  * TCO = total cost of ownership
Fleet scenario calculated by VECTOR21: results
for 2 different scenarios: market success and fleet development of electric cars optimised on the basis of Total Costs of Ownership

Fleet scenario calculated by VECTOR21: results
energy demand and CO₂ emissions of the German car fleet distinguished by technologies for a successful electric mobility Scenario 2

- Final energy demand reduced by 66% due to electric driving and efficiency measures for conventional vehicles
- CO₂ emission (well-to-wheel) reduced by 80% due to renewable electricity and biofuels

source: DLR-FK
Energy systems modelling (REMIX): cost optimised power supply including controlled EV charging and other flexibility options

Installed capacities and power generation profiles from renewables

HVDC lines
long-range power exchange and imports

Transmission grid
based on current European AC grid

Scenario analysis with model REMIX
cost minimised supply in temporal & spatial resolution

model

Electricity demand

Heat demand

Flexible operation of CHP with:
- heat storages
- peak boiler & electric heaters

Electric vehicles (EV)

BEV/hybrids: charging strategies, hourly battery capacities of the fleet connected to the grid

FCEV: flexible on-site H₂ generation

Conventional generation
nuclear, coal, gas power plants

Storages
pumped hydro, compressed air
hydrogen

Demand side management
industry & households, increases system efficiency

Installed capacities and power generation profiles from renewables

GHI

DNI

wind speed

run-off river
Scenario analysis (REMix): effects of EV integration in 2050

Base scenario meets all targets of the Energy Concept (80% reduction of GHG emissions): 27 Mio. EV (53.5 TWh/yr, 40% CL/20% V2G); 87%/80% RE power in D/EU; 57 TWh H₂ demand in transport (D); no net import of electricity.


![Graph]

- **Blue柱状图**: difference to the base scenario: annual surpluses of RE power in TWh/yr
- **Red柱状图**: difference to the base scenario: residual peak load covered by backup power plants in GW

Scenario variants of the base scenario *

- 100% uncontrolled charging
- 100% controlled charging
- 100% bidirectional charging (V2G)
- no EV, less renewables

**peak load** = average of 5% hours of the year with highest load


Funded by

[German Ministry for Economic Affairs and Technology]
Conclusions and Outlook

- A successful fleet scenario (28 % BEV and 34 % EREV in 2050) in line with the political GHG targets requires support and acceptance from all relevant actors and significant technological progress (battery!)

- Battery capacity usable as flexibility option for the power supply system vary significantly from hour to hour (small BEV with 22 kWh capacity: 3 to 14 kWh)

- An optimised integration of EV via (central) charge control leads to significant benefits: reduced RE surpluses around 10% of the electricity demand of EV, between 3.5 and 4.5 GW less backup capacities required (fossil power plants)

- However, other flexibility options such as flexible cogeneration plants with heat storage, transmission grid expansion, electricity import of CSP and pumped hydro may deliver much higher contributions for load balancing

- Regional/local integration of EV leads to other „optimal“ charging strategies. In the future different perspectives need to be analysed in a more integrative way

- Results strongly depend on assumptions (need for more scenario analyses)