Erneuerbare Energien im Verkehr 2050
Ergebnisse und Gedankenfutter aus fünf explorativen 100%-Szenarien für die Forschungsvereinigung Verbrennungskraftmaschinen e.V. (FVV)

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LBST · Ludwig-Bölkow-Systemtechnik GmbH · Munich · Germany
Independent expert for sustainable energy and mobility for over 30 years
- Bridging technology, markets, and policy
- Renewable energies, fuels, infrastructure
- Technology-based strategy consulting, System and technology studies, Sustainability assessment
- Global and long term perspective
- Rigorous system approach – thinking outside the box
- Serving international clients in industry, finance, politics, and NGOs

Reference projects:
- FVV Renewables in Transport 2050
- UBA Power-to-Liquids for Aviation
- BMVI German Mobility & Fuels Strategy (MKS)
- JRC/EUCAR/CONCAWE (JEC) Well-to-Tank Analyses

Agenda

1. Motivation and approach

2. Scenarios

3. Results
   - Greenhouse gas emissions
   - Energy demand
   - Cumulated investments

4. Conclusions
FVV study motivation

- Greenhouse gas reduction targets of $80-95\%_{1990}$ by 2050 will require substantial contributions from the transport sector
- Renewable electricity to become the primary energy source in future
- 100% renewable electricity in transport by 2050 – pie in the sky?
  - $\rightarrow$ 2 archetype scenarios + 1 synthetic mix scenario
- What are the consequences in terms of energy and costs?
- What are determinants for future use of internal combustion engines?
## German «Klimaschutzplan 2050» on the occasion of COP22 in Marrakesh

<table>
<thead>
<tr>
<th>Handlungsfeld</th>
<th>1990 (in Mio. t CO₂-Äq.)</th>
<th>2014 (in Mio. t CO₂-Äq.)</th>
<th>2030 (in Mio. t CO₂-Äq.)</th>
<th>2030 (Minderung in % ggü. 1990)</th>
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<tbody>
<tr>
<td>Energiewirtschaft</td>
<td>466</td>
<td>358</td>
<td>175 – 183</td>
<td>62 – 61 %</td>
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<td>Gebäude</td>
<td>209</td>
<td>119</td>
<td>70 – 72</td>
<td>67 – 66 %</td>
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<td><strong>Verkehr</strong></td>
<td><strong>163</strong></td>
<td><strong>160</strong></td>
<td><strong>95 – 98</strong></td>
<td><strong>42 – 40 %</strong></td>
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<td>Industrie</td>
<td>283</td>
<td>181</td>
<td>140 – 143</td>
<td>51 – 49 %</td>
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<tr>
<td>Landwirtschaft</td>
<td>88</td>
<td>72</td>
<td>58 – 61</td>
<td>34 – 31 %</td>
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<td><strong>Teilsumme</strong></td>
<td><strong>1209</strong></td>
<td><strong>890</strong></td>
<td><strong>538 – 557</strong></td>
<td><strong>56 – 54 %</strong></td>
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<tr>
<td>Sonstige</td>
<td>39</td>
<td>12</td>
<td>5</td>
<td>87%</td>
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<tr>
<td><strong>Gesamtsumme</strong></td>
<td><strong>1248</strong></td>
<td><strong>902</strong></td>
<td><strong>543 – 562</strong></td>
<td><strong>56 – 55 %</strong></td>
</tr>
</tbody>
</table>

Quelle: Klimaschutzplan 2050 der Bundesregierung, 11.11.2016, S. 26/27

23 November 2016
Ludwig-Bölkow-Systemtechnik GmbH
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Two distinct transportation demand scenarios | DE | HIGH, LOW

Scenario developments 2010–2050 (figures rounded)

- **HIGH transport demand scenario**
  [BMVI VP 2030/MKS 2050]
  - Passenger +30%
  - Freight +60%

- **LOW transport demand scenario**
  [eMobil 2050 „Regional“]
  - Passenger -25%
  - Freight +20%
Target scenario – gradual shift from today to 100% renewable PtX by 2050

- Gasoline/kerosene/diesel
- Methanol
- Methane
- Hydrogen

Renewable share in the fuels (per MJ fuel)

PtL · Power-to-Liquids
PtX · Power-to-Anything

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Definition of three distinct fuel/powertrain scenarios

- **PTL** | Conservative scenario based on well established fuels/powertrains/infrastructures, incl. ICE mild hybrids with power-to-liquids dominating all transportation modes
  → high fuel demand

- **FVV** | A mix of currently discussed options, comprising ambitious ICE development progress, incl. ICE hybrids, REEV, BEV, FCEV
  → medium fuel demand

- **eMob** | Derived from the study “eMobil 2050” [Öko-Institut 2015], with a dominance of electrified drivetrains
  → low fuel demand
### Fuel/powertrain scenario | New car registrations

#### PTL CAR [%\_new\_reg]

<table>
<thead>
<tr>
<th>Year</th>
<th>ICE Gasol./Diesel</th>
<th>ICE Methane</th>
<th>Hybrid Gasol./Diesel</th>
<th>Hybrid Methane</th>
<th>REEV Gasol./Diesel</th>
<th>REEV Methane</th>
<th>BEV</th>
<th>FCEV</th>
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<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>2020</td>
<td>80</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2030</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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</tr>
</tbody>
</table>

#### FVV CAR [%\_new\_reg]

<table>
<thead>
<tr>
<th>Year</th>
<th>ICE Gasol./Diesel</th>
<th>ICE Methane</th>
<th>Hybrid Gasol./Diesel</th>
<th>Hybrid Methane</th>
<th>REEV Gasol./Diesel</th>
<th>REEV Methane</th>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>4</td>
<td>1</td>
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<td>0</td>
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<td>55</td>
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<td>25</td>
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<td>0</td>
<td>37</td>
<td>2</td>
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<td>16</td>
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<td>0</td>
<td>70</td>
<td>0</td>
<td>20</td>
<td>10</td>
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#### eMob CAR [%\_new\_reg]

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<th>Year</th>
<th>ICE Gasol./Diesel</th>
<th>ICE Methane</th>
<th>Hybrid Gasol./Diesel</th>
<th>Hybrid Methane</th>
<th>REEV Gasol./Diesel</th>
<th>REEV Methane</th>
<th>BEV</th>
<th>FCEV</th>
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<tbody>
<tr>
<td>2010</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2020</td>
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<td>5</td>
<td>3</td>
<td>0</td>
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<tr>
<td>2030</td>
<td>68</td>
<td>5</td>
<td>6</td>
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<tr>
<td>2040</td>
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<td>0</td>
<td>10</td>
<td>0</td>
<td>17</td>
<td>0</td>
<td>72</td>
<td>0</td>
</tr>
<tr>
<td>2050</td>
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<td>0</td>
<td>12</td>
<td>0</td>
<td>82</td>
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</tbody>
</table>
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Greenhouse gas emissions (example FVV scenario)
Greenhouse gas emissions | DE | All transport | «FVV»

**FVV + HIGH**

**by fuel**
- Non-CO2-GHG vehicle
- Methanol
- H2
- Electricity mix (train)
- Electricity mix (0.4 kV)
- CH4
- Diesel/Kerosene
- Gasoline

**by mode**
- Aviation
- Ships (freight)
- Trucks
- Rail (freight)
- Rail (passenger)
- Buses
- Passenger vehicles

- Climate impacts from high-altitude emissions (aviation) not included

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Final fuel demand, electricity demand
Fuel demand (TWh/a) | DE | All transport | «FVV»

- Growth in HIGH transport demand overcompensates efficiency improvements
- Relative importance of trucks and aviation in fuel demand increases
- Thereof, notably international aviation

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- Total electricity demand in 2050 may be a factor 2 to 4 of today’s electricity demand.
- All scenarios would likely require renewable energy imports.
... and cumulated investments until 2050
Cumulated investments until 2050 | Methodology

- The cumulated investments consist of the following elements:
  - Renewable power plants
  - PtX production plants
  - Infrastructure for fuel transport & distribution

- Investments for end-of-life replacements are included in the cost model with a PtX plant lifetime of 25 years.

- Learning curves for electrolysers assumed, i.e. the 1\textsuperscript{st} PtX production plant is more expensive than the n\textsuperscript{th} one.

- BEV home-charging assumed.

- Vehicle costs not included.
Cumulated investments until 2050 | Germany

For comparison 2014 in Germany:
- Gross domestic product (GDP) = 2900 billion €/a
- >70 GW renewable power (38 GW wind onshore, 3 GW wind offshore, 39 GW PV)

- PTL: 6200 H2 refuelling stations
- PtX production plants
- FVV: 4600 CH4 refueling stations
- eMob: 360-900 GW RES power plants
- BEV: Home charging

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System integration of fluctuating renewable power generation
Efficiency vs. renewables integration
(Scaling indicative/for educational purpose)

- Trade-off between efficiency and renewable power integration (“Systemdienlichkeit”)
- Robust option: Hydrogen
- Sole option providing zero well-to-wheel emissions AND long-term energy storage: Hydrogen

Efficiency
Propulsion+Upstream

Storage density
& Demand flexibility

Electric powertrain
Zero (local) emissions

demand flexibility over hours/day(s)
Energy storage over days/weeks/months

demand flexible up to few hours

BEV
Charging

PTG
Hydrogen

PTG
Methane

PTL
Gasoline, Diesel, ...

EV
Overhead line

Demand flexible add. measures
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Conclusions from the FVV Future Fuel study in a nutshell

- Transportation demand development (pkm, tkm) is strongest driver for fuel/electricity demand.
- PtX fuel costs could half between 2015 and 2050; PtL imports ~20% lower in cost. → Further cost reductions are subject to location-specific business cases.
- PtX costs are dominated by electricity costs, which strongly depends on the fuel choice (H₂, CH₄, PTL) and associated plant efficiencies.
- Fuel distribution infrastructure costs are negligible compared to the upstream investments required for any of the scenarios analysed.
- Cumulated investments for Energiewende (energy transition) in the transportation sector seem manageable for any of the scenarios analysed.
- All scenarios analysed will probably exceed technical/acceptable renewable electricity potentials in Germany. Import of PtL (if any) is likely for cost reasons.
- Transport must get more electric, with regard to the fuel and the propulsion system.
Literature

P. Schmidt, W. Zittel, W. Weindorf, T. Raksha (LBST)
Renewables in Transport 2050 – Empowering a sustainable mobility future with zero emission fuels from renewable electricity – Europe and Germany
Research Association for Combustion Engines e.V. (ed.)
FVV-Report 1086 / 2016

→ Download
Acknowledgement

This study was financed by the FVV and supported by members of the FVV Working Group «Future Fuels»
Technical renewable power generation potentials
Renewable electricity potentials in Germany and EU-28

- Germany and the EU have (very) high technical renewable electricity potentials
  - DE: ~1000 TWh/a potential vs. ~500 TWh net electricity consumption
  - EU: ~11000 TWh/a potential vs. ~2800 TWh net electricity consumption
- Only ~11% (DE) and ~6% (EU28) if this potentials are currently used for renewable power production
- The limits to renewable power growth seem to be more of an acceptance issue than costs
- [ISE 2015] states PV electricity production costs of 2-4 €ct/kWh in Southern and Central Europe by 2050
- Renewable power potentials assessed for solarthermal power plants could also be exploited with photovoltaics
Renewable electricity potentials in Germany (bars can be stacked)

Technical potential (TWh/yr)

- Wind/onshore
- Wind/offshore
- PV
- Hydro
- Geothermal

Net electricity consumption 2014: 521 TWh/yr **

Maximum

Bandwidth for technical renewable energy potentials

Minimum

Potential already exploited*

Assumption in this study

Σ 1000 TWh/yr

Data: [BMU 2010], [BMU 2012], [BWE 2013], [ISE 2015], [IWES_PV 2012], [IWES 2012], [Quaschning 2013], [TAB 2003], [UBA 2013]

* 2014 data: [AGEB 2015] provisional as per 08/2015
** 2014 data: [BDEW 2015] provisional as per 08/2015

Ludwig-Bölkow-Systemtechnik GmbH (LBST), 2015-10-05
CO₂ avoidance costs
CO₂ avoidance costs well-to-tank [€/t CO₂-eq] for PtX in DE

Benchmarks: Fuels from crude oil (0 €/t CO₂)

Least-cost short-term: Electricity

Least-cost long-term: Electricity and CGH₂