VDI-Fachtagung «Innovative Antriebe» · Dresden · 23. November 2016

Erneuerbare Energien im Verkehr 2050

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

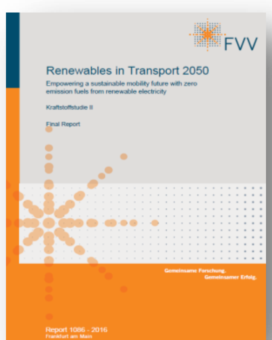
Patrick R. Schmidt · Werner Weindorf · Werner Zittel

LBST · Ludwig-Bölkow-Systemtechnik GmbH · Munich · Germany

LBST · Ludwig-Bölkow-Systemtechnik GmbH

ludwig bölkow
systemtechnik

- 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

http://www.lbst.de/ressources/docs2016/FVV_H1086_Renewables-in-Transport-2050-Kraftstoffstudie_II.pdf

Agenda

1. Motivation and approach
2. Scenarios
3. Results
   - Greenhouse gas emissions
   - Energy demand
   - Cumulated investments
4. Conclusions

ludwig bölkow systemtechnik

FVV study motivation

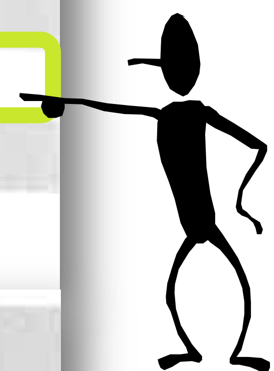
- Greenhouse gas reduction targets of 80-95%$_{1990}$ by 2050 will require substantial contributions from the transport sector
- Renewable electricity to become the primary energy source in future
- 100% renewable electricity in transport by 2050 – pie in the sky?

  → 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

ludwig bölkow systemtechnik

Handlungsfeld	1990 *(in Mio. t CO_2-Äq.)*	2014 *(in Mio. t CO_2-Äq.)*	2030 *(in Mio. t CO_2-Äq.)*	2030 (Minderung in % ggü. 1990)
Energiewirtschaft	466	358	175 – 183	62 – 61 %
Gebäude	209	119	70 – 72	67 – 66 %
Verkehr	163	160	95 – 98	42 – 40 %
Industrie	283	181	140 – 143	51 – 49 %
Landwirtschaft	88	72	58 – 61	34 – 31 %
Teilsumme	1209	890	538 – 557	56 – 54 %
Sonstige	39	12	5	87%
Gesamtsumme	**1248**	**902**	**543 – 562**	**56 – 55 %**



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

Agenda

1. Motivation and approach
2. Scenarios
3. Results
   - Greenhouse gas emissions
   - Energy demand
   - Cumulated investments
4. Conclusions

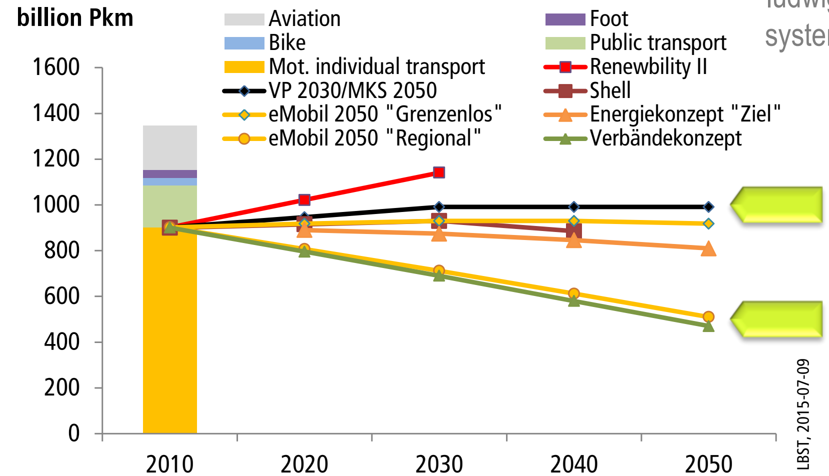
Two distinct transportation demand scenarios | DE | HIGH, LOW

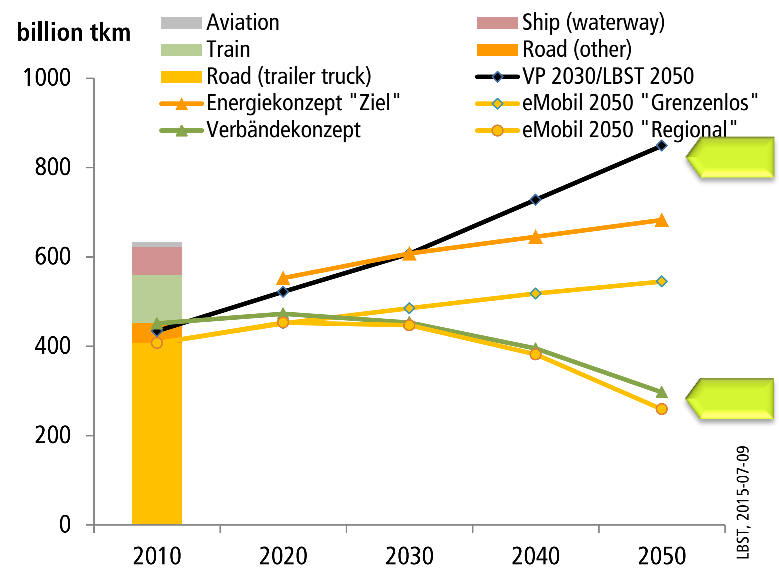
ludwig bölkow systemtechnik

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%





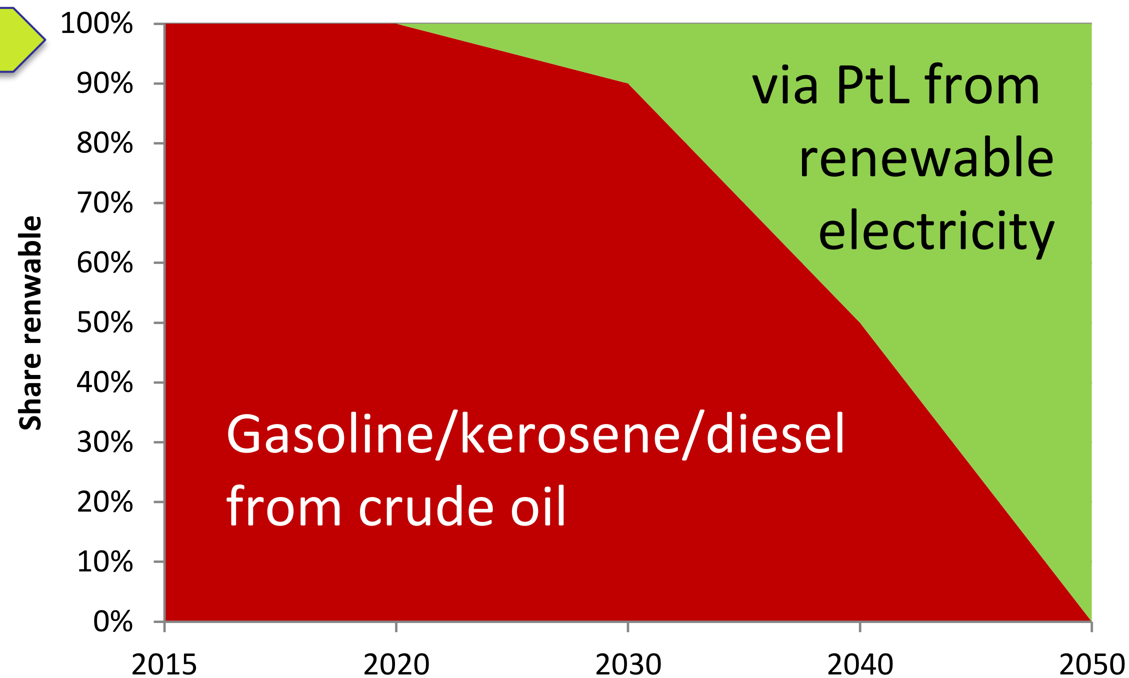
BMVI · German Federal Transport Ministry
MKS · German Mobility & Fuels Strategy

Renewable share in the fuels (per MJ fuel)

ludwig bölkow
systemtechnik

Target scenario – gradual shift from today to 100% renewable PtX by 2050

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



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

Definition of three distinct fuel/powertrain scenarios

ludwig bölkow
systemtechnik

- 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 [$\%_{new\text{-}reg}$]	ICE Gasol./ Diesel	ICE Methane	Hybrid Gasol./ Diesel	Hybrid Methane	REEV Gasol./ Diesel	REEV Methane	BEV	FCEV
2010	100	0	0	0	0	0	0	0
2020	80	0	20	0	0	0	0	0
2030	40	0	60	0	0	0	0	0
2040	10	0	90	0	0	0	0	0
2050	0	0	100	0	0	0	0	0

FVV CAR [$\%_{new\text{-}reg}$]	ICE Gasol./ Diesel	ICE Methane	Hybrid Gasol./ Diesel	Hybrid Methane	REEV Gasol./ Diesel	REEV Methane	BEV	FCEV
2010	100	0	0	0	0	0	0	0
2020	36	5	45	2	6	0	4	1
2030	0	0	55	5	25	0	10	5
2040	0	0	37	2	45	0	16	9
2050	0	0	0	0	70	0	20	10

eMob CAR [$\%_{new\text{-}reg}$]	ICE Gasol./ Diesel	ICE Methane	Hybrid Gasol./ Diesel	Hybrid Methane	REEV Gasol./ Diesel	REEV Methane	BEV	FCEV
2010	100	0	0	0	0	0	0	0
2020	86	5	3	0	3	0	3	0
2030	68	5	6	0	9	0	12	0
2040	0	0	10	0	17	0	72	0
2050	0	0	5	0	12	0	82	0

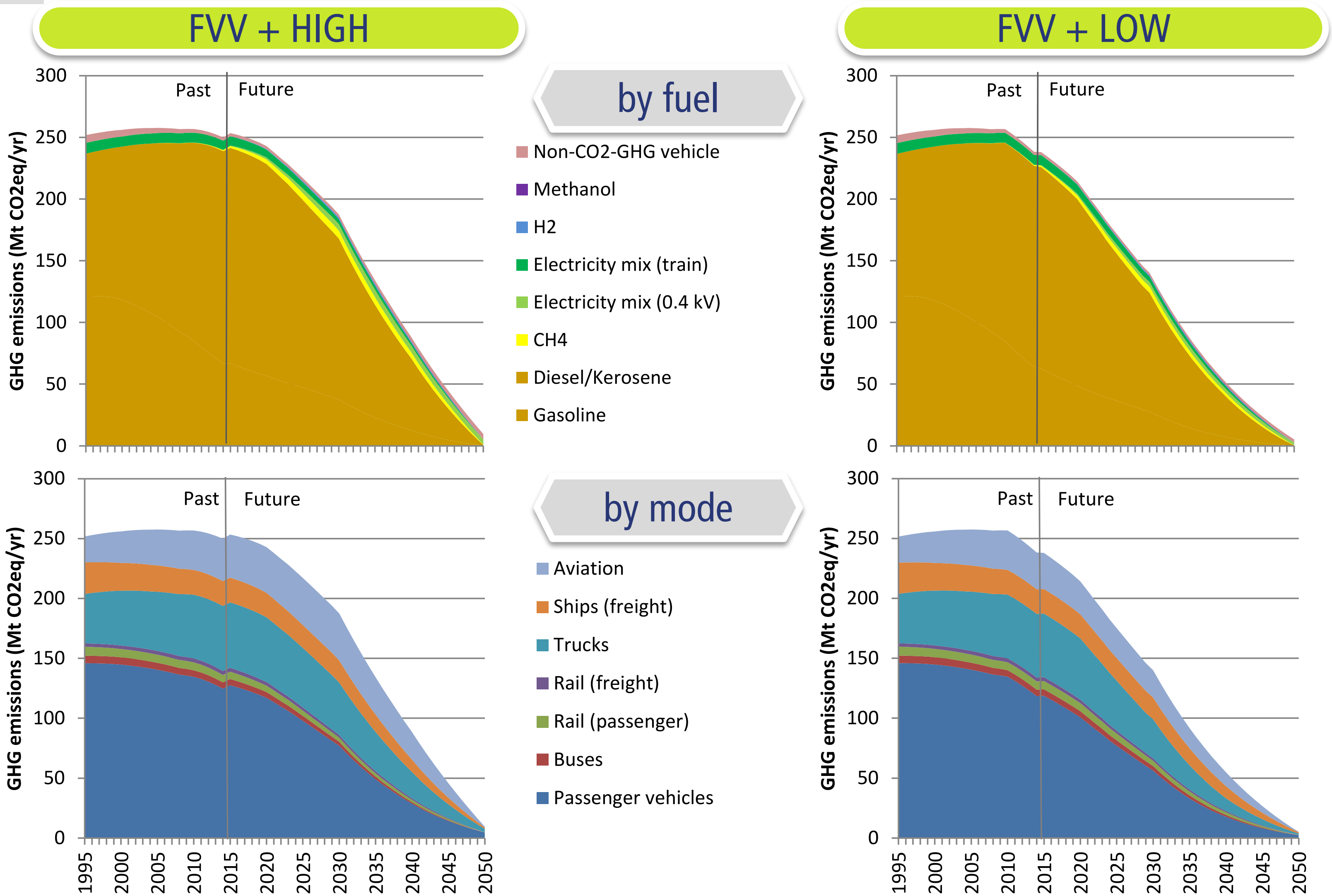
Agenda

ludwig bölkow
systemtechnik

1. Motivation and approach
2. Scenarios
3. Results
   - Greenhouse gas emissions
   - Energy demand
   - Cumulated investments
4. Conclusions

Greenhouse gas emissions (example FVV scenario)

Greenhouse gas emissions | DE | All transport | «FVV»



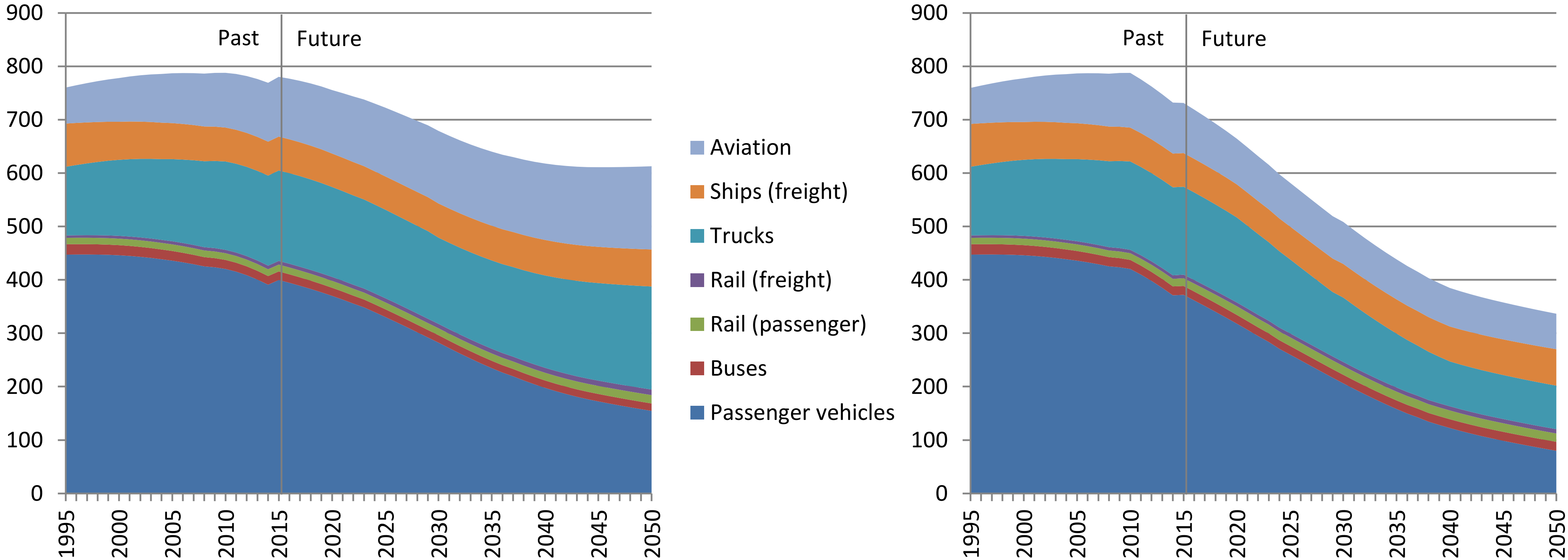
- Climate impacts from high-altitude emissions (aviation) not included

ludwig bölkow
systemtechnik

Final fuel demand, electricity demand

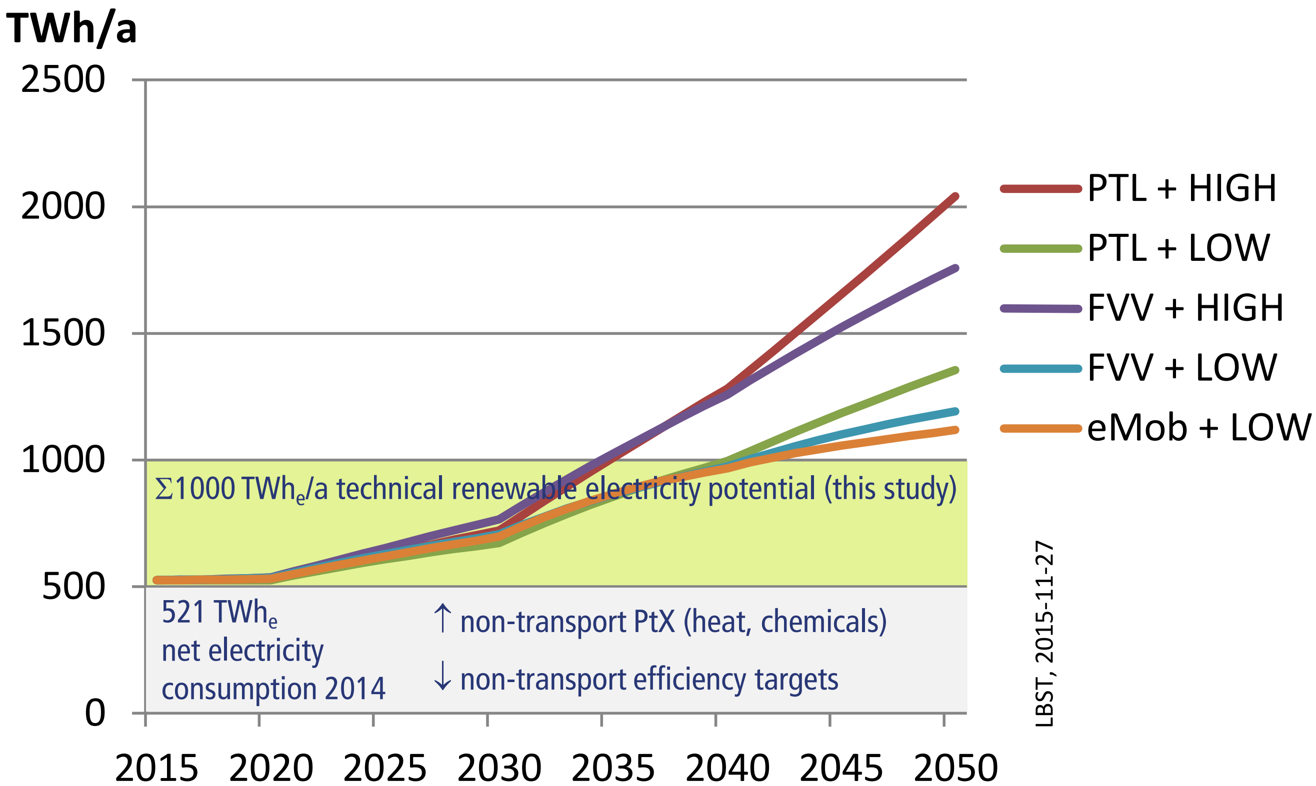
Fuel demand (TWh/a) | DE | All transport | «FVV»

FVV + HIGH | **FVV + LOW**



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

Electricity demand (TWh_e/a) | DE | Today + transportation



- 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

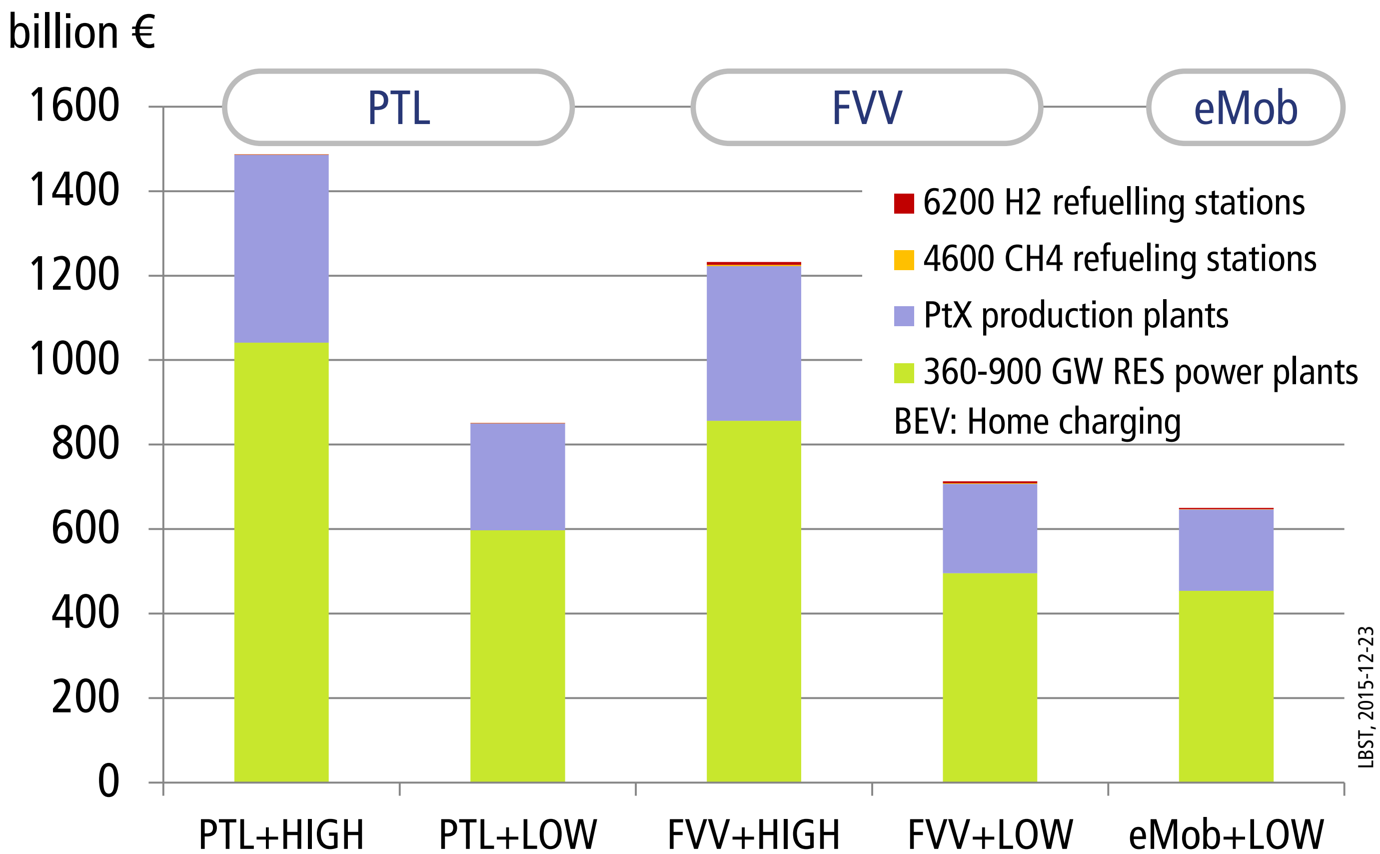
Cumulated investments until 2050 | Methodology

ludwig bölkow
systemtechnik

- 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 1st PtX production plant is more expensive than the nth one.
- BEV home-charging assumed.
- Vehicle costs not included.

Cumulated investments until 2050 | Germany

ludwig bölkow systemtechnik



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)

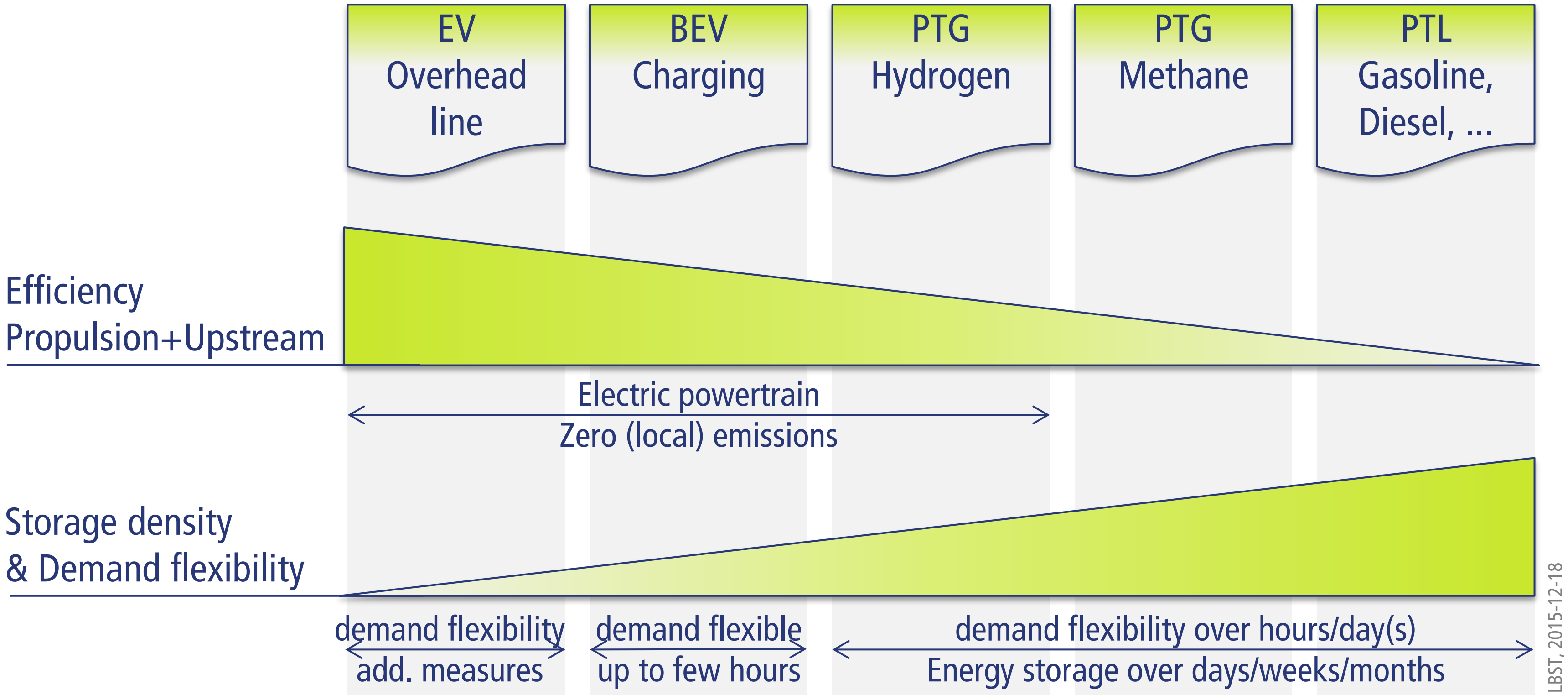
ludwig bölkow
systemtechnik

System integration of fluctating renewable power generation

Efficiency vs. renewables integration

(Scaling indicative/for educational purpose)

ludwig bölkow systemtechnik



- 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

Agenda

ludwig bölkow
systemtechnik

1. Motivation and approach
2. Scenarios
3. Results
   - Greenhouse gas emissions
   - Energy demand
   - Cumulated investments
4. Conclusions

Conclusions from the FVV Future Fuel study in a nutshell

ludwig bölkow
systemtechnik

- 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 (H_2, CH_4, 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.

pkm · person kilometre
tkm · tonne kilometre
PtX · Power-to-anything
PtL · Power-to-liquids

Literature

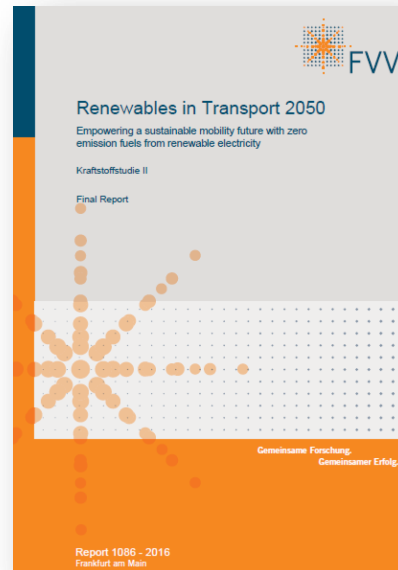
ludwig bölkow
systemtechnik

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


FVV

Renewables in Transport 2050

Empowering a sustainable mobility future with zero emission fuels from renewable electricity

Kraftstoffstudie II

Final Report

Gemeinsame Forschung.
Gemeinsamer Erfolg.

Report 1086 - 2016
Frankfurt am Main

→ Download

http://www.fvv-net.de/en/download/renewables-in-transport-2050/renewables-in-transport-2050.html

LBST Experts

Patrick Schmidt (Dipl.-Ing.)

T: +49 (0)89 608110-36
E: Patrick.Schmidt@LBST.de

Dr. Werner Zittel

Werner Weindorf (Dipl.-Ing.)

Tetyana Raksha (Dipl.-Ing.)

LBST · Ludwig-Bölkow-Systemtechnik GmbH

Daimlerstr. 15 · 85521 Munich/Ottobrunn · Germany
http://www.lbst.de

Acknowledgement

This study was financed by the FVV
and supported by members of the
FVV Working Group «Future Fuels»

ludwig bölkow
systemtechnik

ANNEX

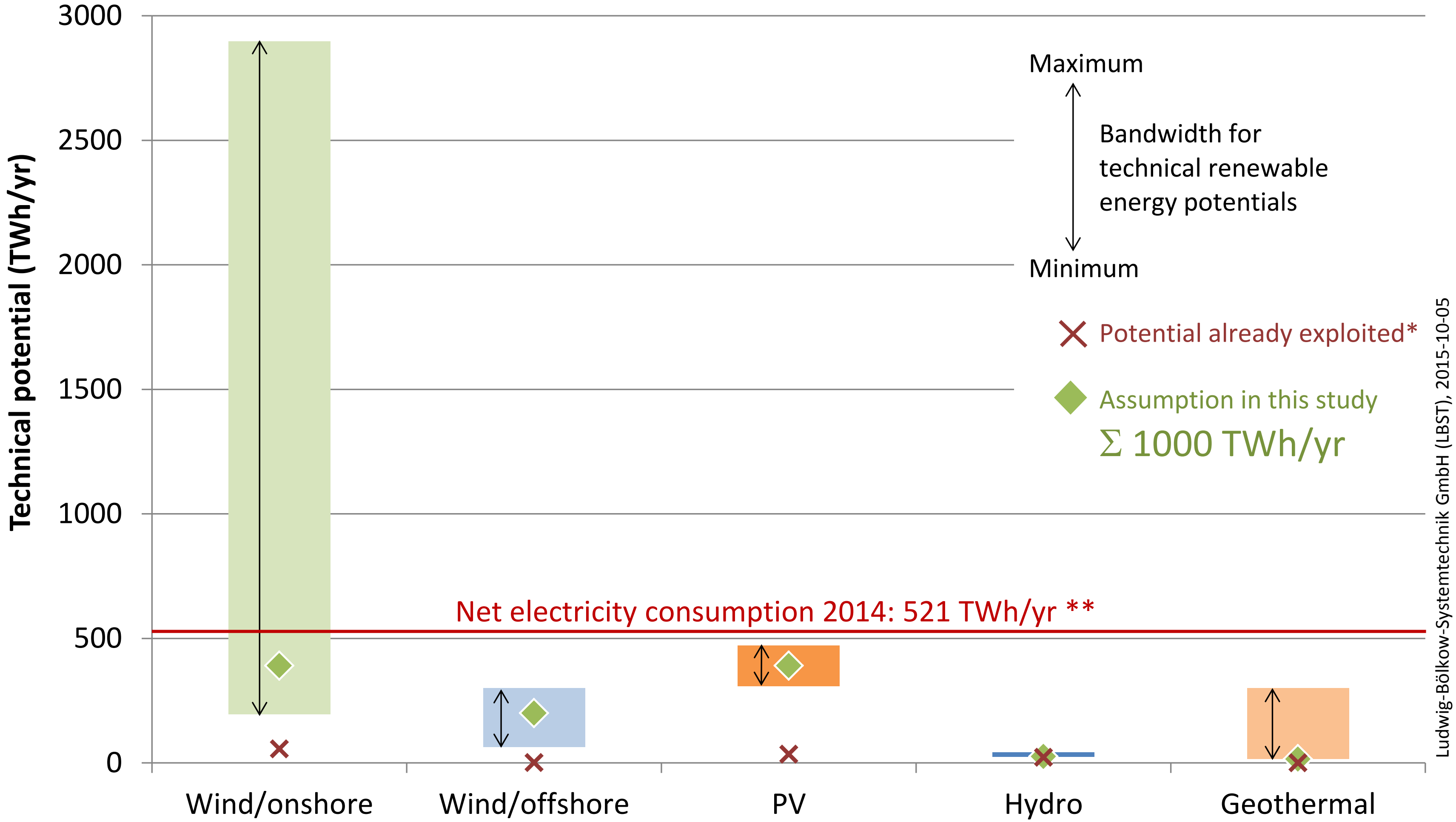
Technical renewable power generation potentials

Renewable electricity potentials in Germany and EU-28

ludwig bölkow systemtechnik

- 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)



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

CO_2 avoidance costs

CO_2 avoidance costs well-to-tank [€/t CO_{2-eq}] for PtX in DE

ludwig bölkow systemtechnik