Conference “Energy Systems in Transition: Inter- and Transdisciplinary Contributions”
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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

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.

Vehicle simulation
vehicle concepts,
specif. electricity demand
& battery SOC temporally
(Dymola/Modelica)

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

Hourly user profiles
basis: real world data

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hourly input data (per vehicle class): demand and min./ max. SOC of fleet

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

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hourly data of a year per model region:

charging profiles (BEV, EREV, small, medium, large)
power generation, regional exchange and costs

Simulation of power Transmission grid (HV)
limitations, transfer capacities,
Need for expansion

(UCTE-model of FGH, Aachen)

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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: CO_2 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

Moderate, current technologies! Scenario 1 → 250

Optimistic, new technologies! Scenario 2 → 400

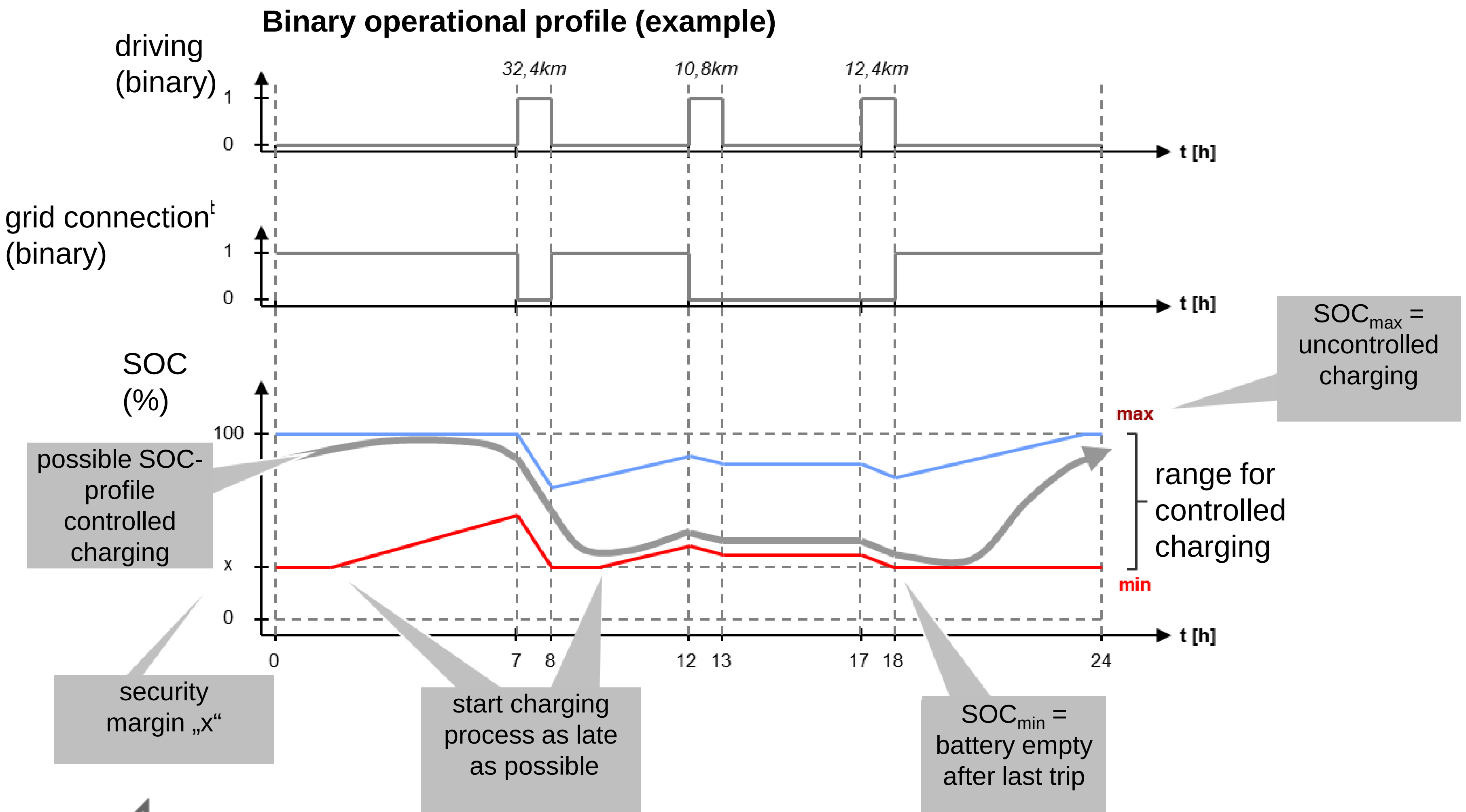
Assumptions regarding grid connection

	likelihood
at work	50%
education	40%
business trip	10%
escort	10%
private	10%
shopping	30%
leisure activities	30%
others	10%
after last trip	70%

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)



source: DLR-FK * SOC = state of charge

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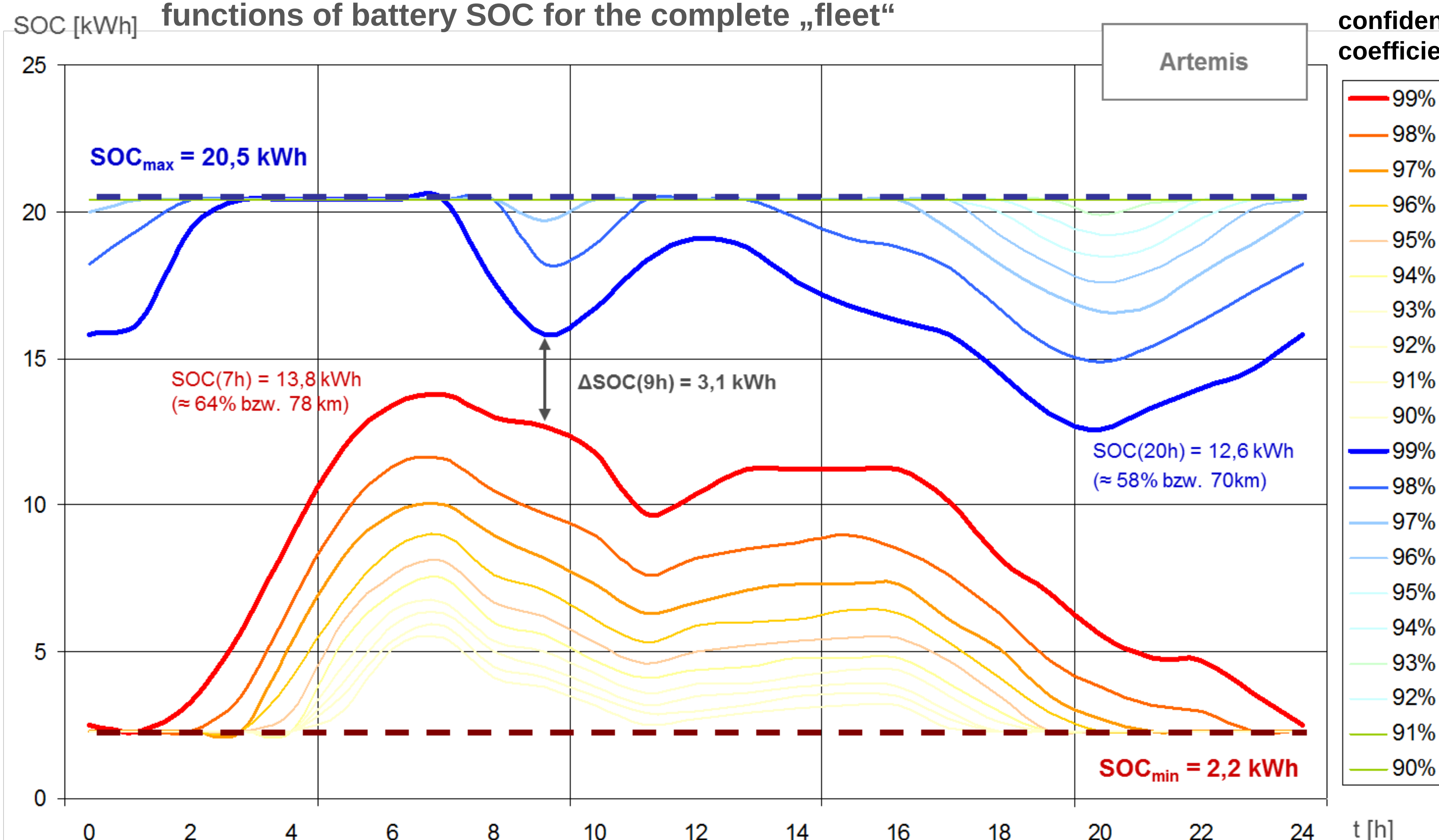
Operational profiles of the fleet: example „small BEV“

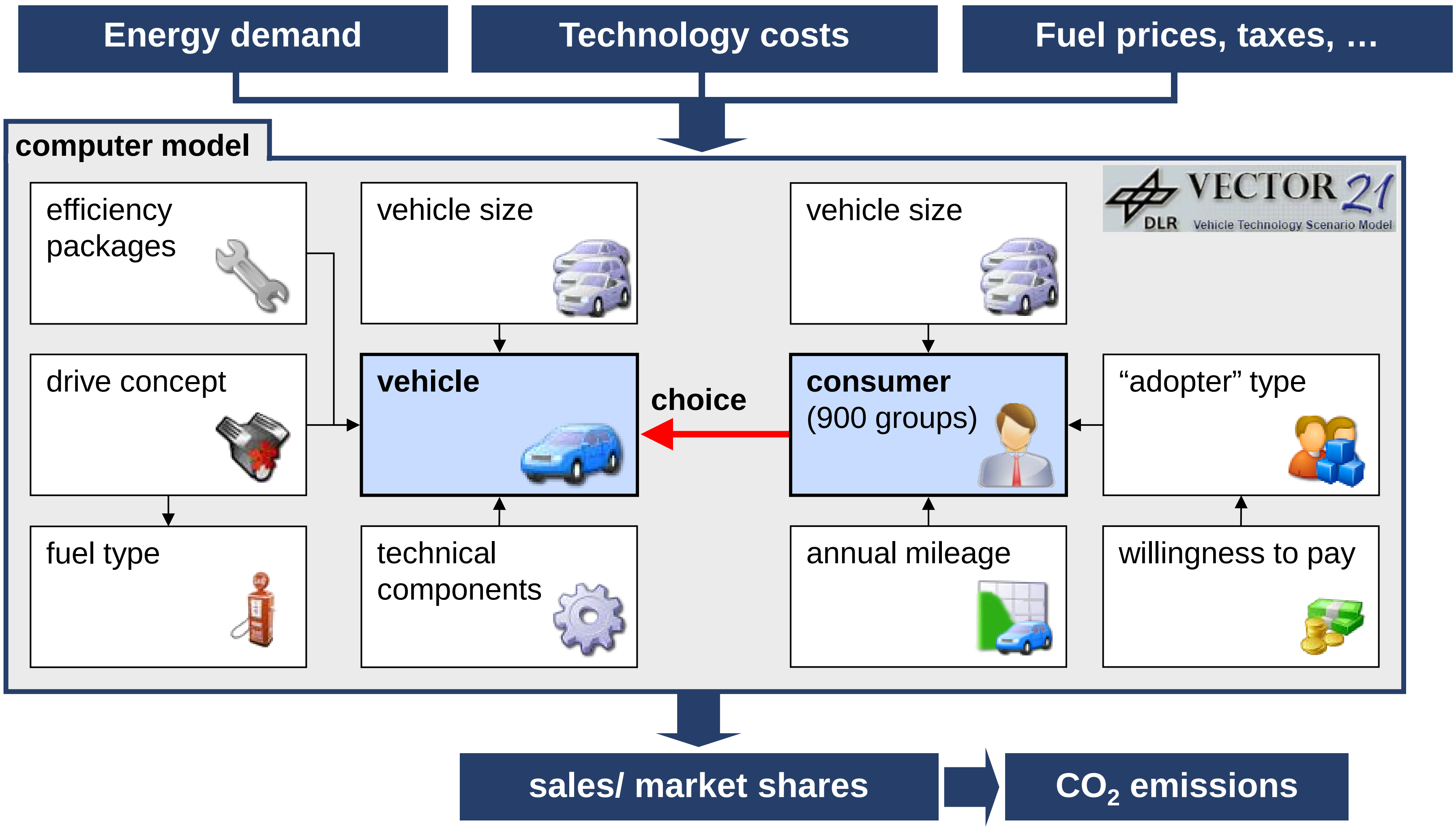
derived from all suitable profiles (MiD 2008) by overlapping the distribution functions of battery SOC for the complete „fleet“



source: DLR-FK

Market and fleet development

Simulation of technology development and consumer demand (model VECTOR21)



source: DLR-FK

Fleet scenario calculated by VECTOR21:

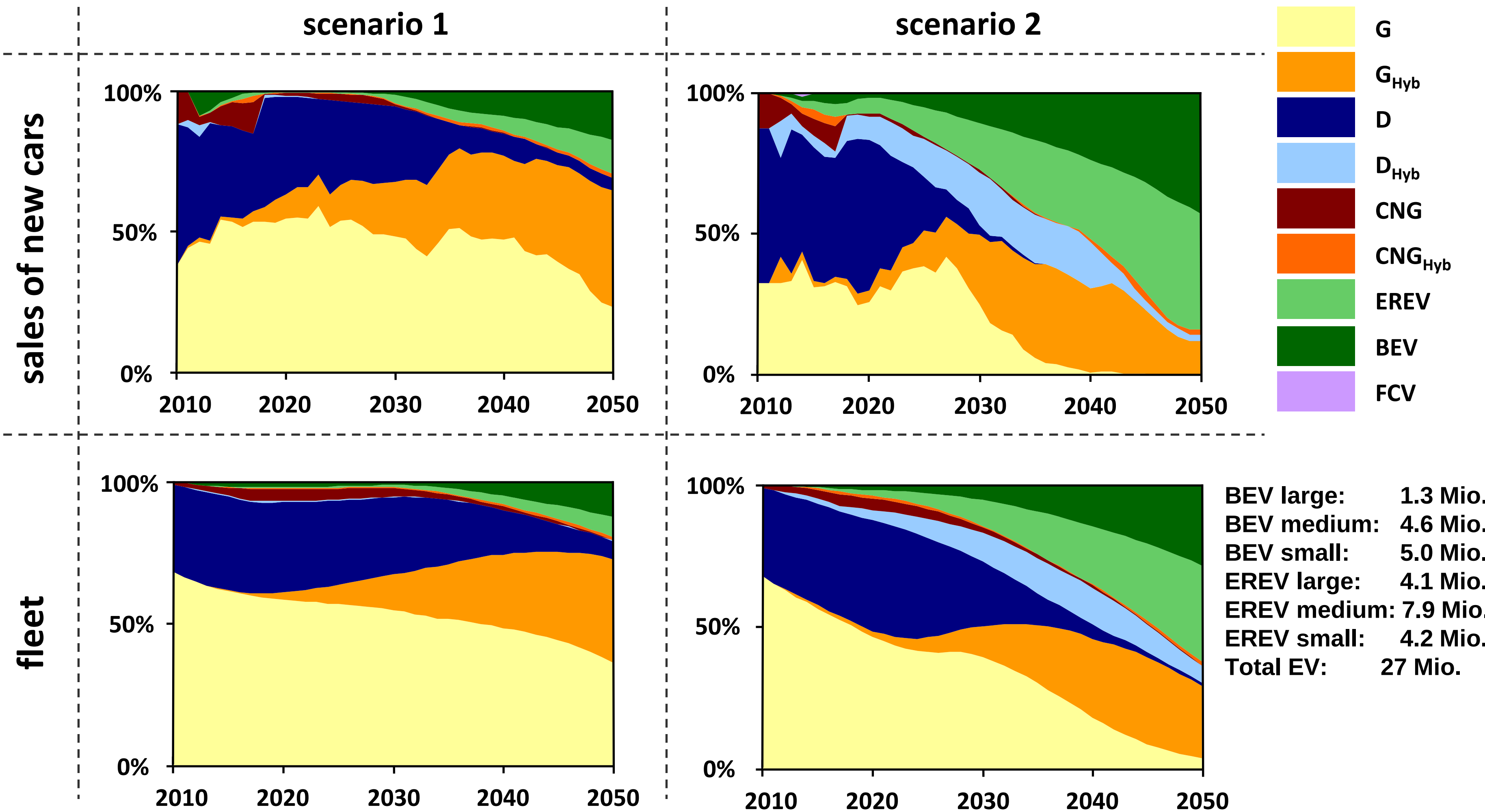
main assumptions influencing vehicle sales of different consumer groups (based on TCO*) for Scenario 2 „successful“

assumptions		2010	2020	2030	2040	2050	Source
Oil price	**[€/bbl]**	60	80	130			DLR analysis
CNG tax	**[%]**	20	as of 2018: 100				Current law
Electricity price	**[€ ct/kWh]**	21,5	34,1	37,3	36,4	35,7	BMU study: for RE „Leitszenario 2010“
H_2 price	**[€ ct/kWh]**	22,3	39,0	37,6	36,5	35,5	calculated
Share H_2 from electrolysis	**[%]**	100%					DLR analysis
CO_2 intensity electricity	**[g/kWh]**	540	510	21 (as of 2025)			„Leitszenario 2010“, 100% RE as of 2025
CO_2 intensity H_2	**[g/kWh]**	648	612	25 (as of 2025)			calculated
CO_2 limit (EU level)	**[g CO_2/km]**	2015: 130	118	97	80	70	Current law and BMU
CO_2 penalties	**[€/ (g CO_2/km)]**	95					Current law, DLR analysis
Willingness-to-pay	**[%]**	0-20					Rogers 1995, consumer analysis
Segments of new cars	**[S/M/L %]**	(25/55/20)	(28/50/22)	(30/45/25)			KBA

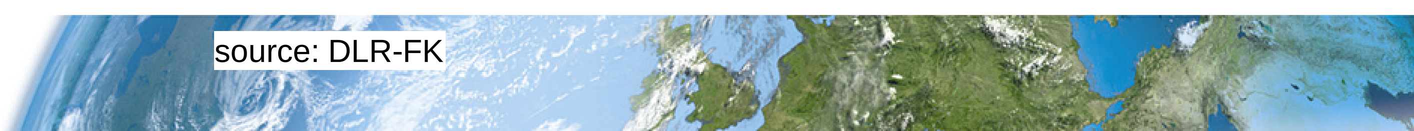
source: DLR-FK * TCO = total cost of ownership

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



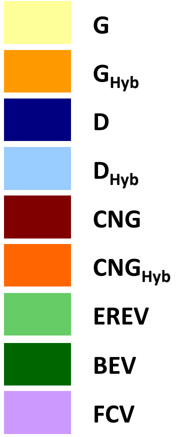
vehicle types: G: gasoline, D: diesel, CNG: gas, Hyb: hybrid variants, EREV: range extender, BEV: battery, FCV: fuel cells



source: DLR-FK

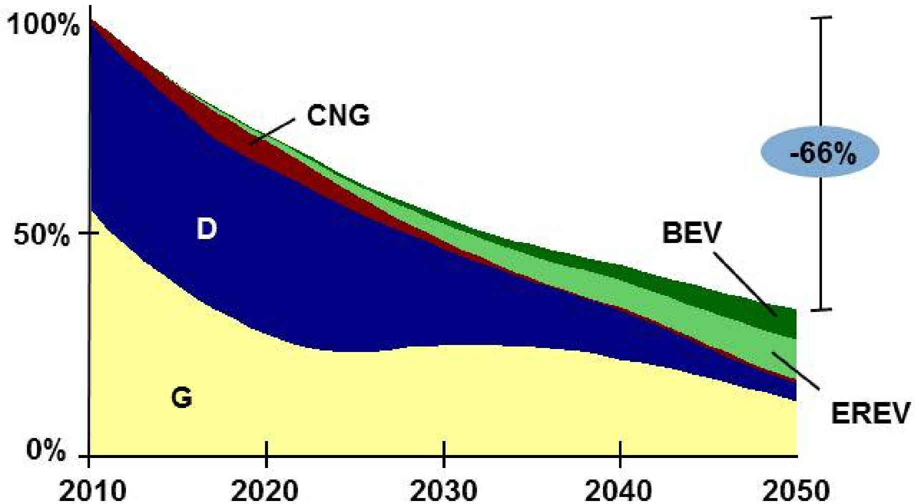
Fleet scenario calculated by VECTOR21: results

energy demand and CO_2 emissions of the German car fleet distinguished by technologies for a successful electric mobility Scenario 2

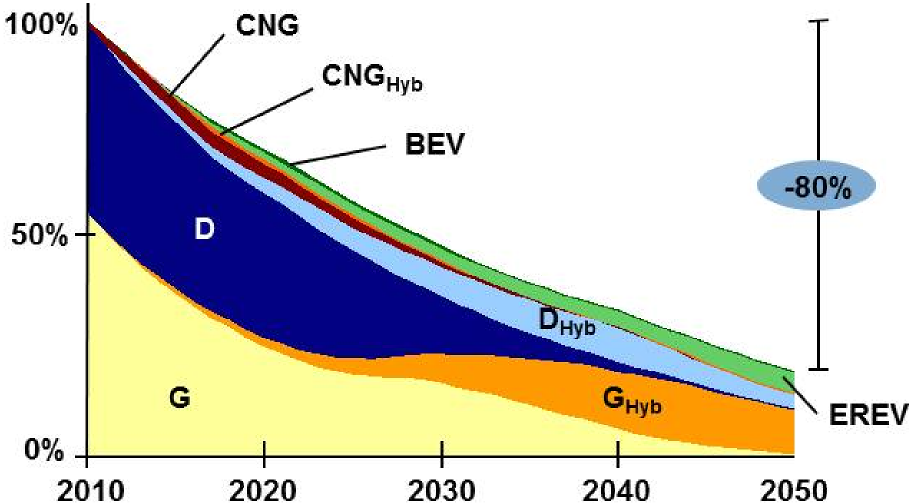


- Final energy demand reduced by 66% due to electric driving and efficiency measures for conventional vehicles
- CO_2 emission (well-to-wheel) reduced by 80% due to renewable electricity and biofuels

Final energy demand total car fleet



CO2 emissions total car fleet

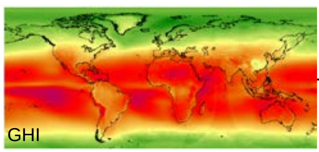


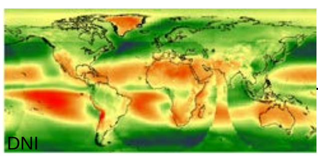
source: DLR-FK

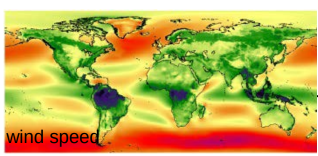
Energy systems modelling (REMix): cost optimised power supply

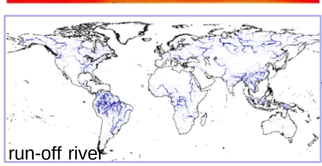
including controlled EV charging and other flexibility options

Installed capacities and power generation profiles from renewables









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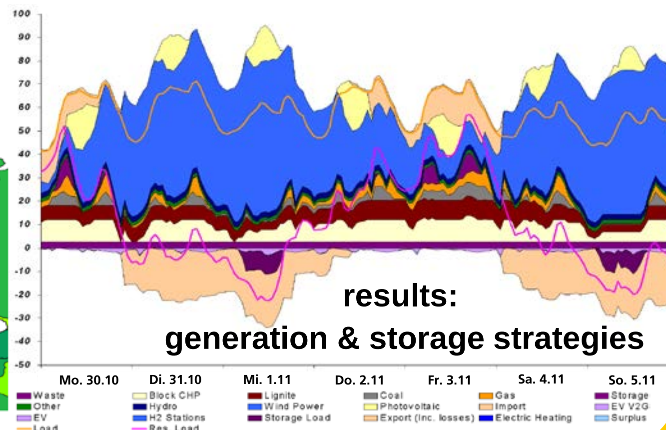
HVDC lines
long-range power exchange and imports

Transmission grid
based on current European AC grid

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

model



results: generation & storage strategies

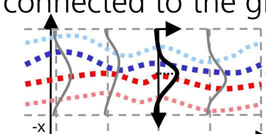
Electricity demand

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 H_2 generation

Conventional generation
nuclear, coal, gas power plants

Storages
pumped hydro
compressed air
hydrogen

Demand side management
industry & households, increases system efficiency

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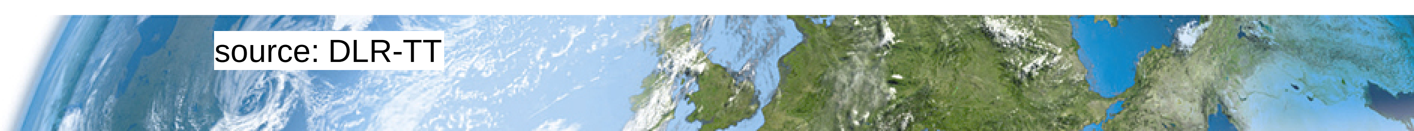
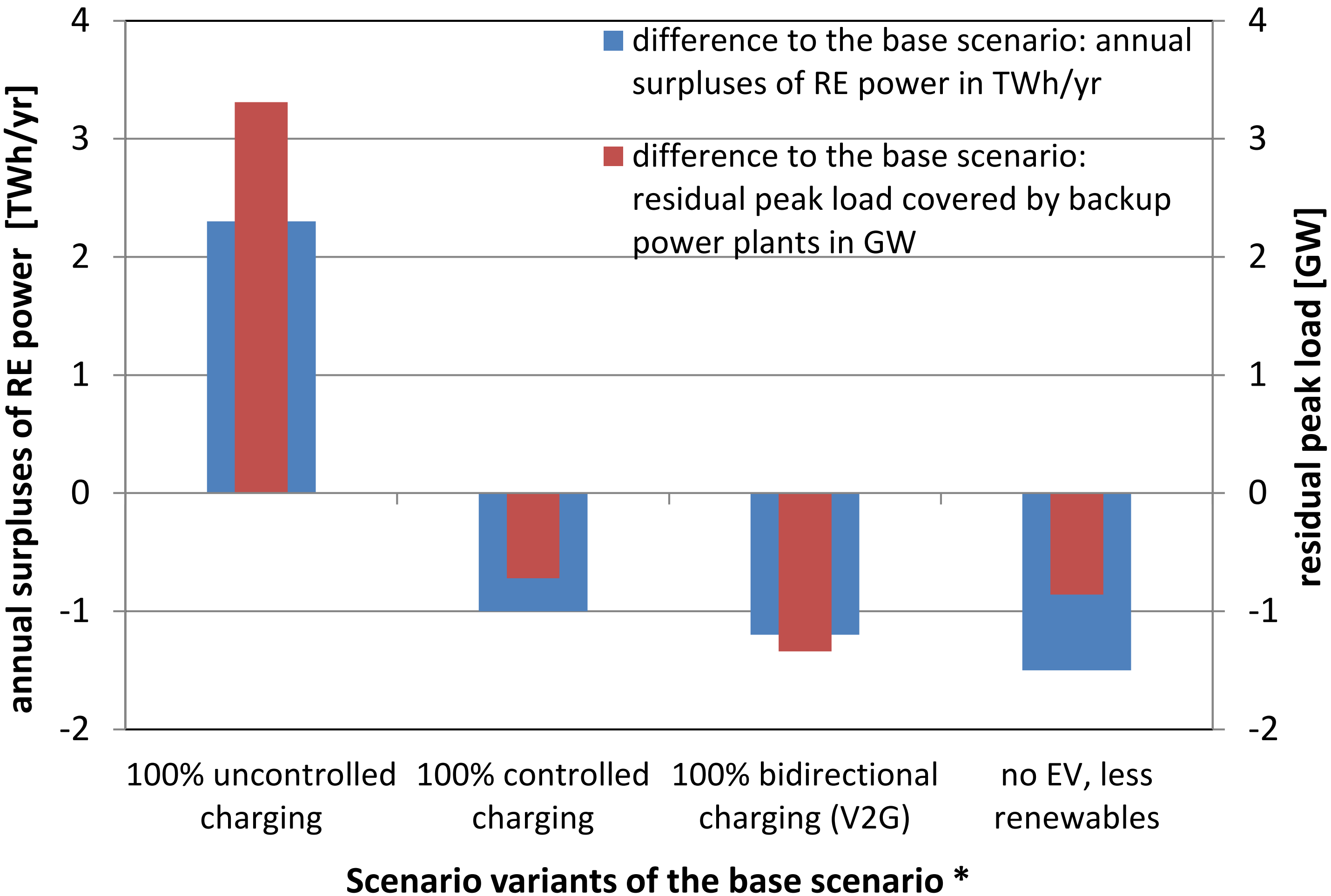


source: DLR-TT

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 H_2 demand in transport (D); no net import of electricity



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

Source: Perspektiven von Elektro-/Hybridfahrzeugen in einem Versorgungssystem mit hohem Anteil dezentraler und erneuerbarer Energiequellen. Schlussbericht DLR Stuttgart/FhG ISE Freiburg/IfHT RWTH Aachen, FGH Aachen. Juli 2012

funded by

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PtJ Projektträger Jülich Forschungszentrum Jülich

source: DLR-TT

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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)