INSTITUT FÜR ENERGIE- UND UMWELTFORSCHUNG HEIDELBERG

Introduction to Bus Electro-Mobility Development in Germany

Hinrich Helms, Fabian Bergk and Nicolas Legner

Beijing, November 20th 2015

The ifeu

- In 1971, professors and students founded the AGU:

  Working Group on Environmental Protection at the University of Heidelberg

- The need for independent environmental research led to the foundation of ifeu as a non-profit organisation in 1978.

- In 1992, ifeu was incorporated been a GmbH (limited liability company) with non-profit status as of 1999.

20 Jahre ifeu-Institut, M. Schmidt, U. Höpfner (Hrsg.), 1998, Heidelberg

The ifeu

- At present, ifeu has a staff of about 60 scientists who work as an interdisplinary team with a broad variety of expertise on current environmental topics.
- The institute is committed to the goal of a sustainable society.

Financing

- Financing solely through project-related funds

  to allow a politically and economically independent ecological research.

  - Approximately two-third of the research projects and assessments are commissioned by federal and state ministries, local authorities, the Environmental Protection Agency and other public bodies.

  - A third of the orders come from the private sector.

Clients (selection)

European Union

European Environment Agency

European Commission

ETC RWM
European Topic Centre on Resource and Waste Management

Departments of Federal, State and Local Governments

Federal Ministry Department (Environment, Economy, Transport)

State Departments

World Bank, UNEP, FAO, etc.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

iea

UNFCCC

UNIDO

FAO FIAT PANIS

THE WORLD BANK

Non-governmental Organisations

NABU

GREENPEACE

VCD Verkehrsclub Deutschland

BUND für Umwelt und Naturschutz Deutschland e.V.

Transport and Logistic Service Providers

DB

Deutsche Post

Clients (selection)

Industrial Associations

PlasticsEurope

edana

ACE Auto Club Europa

DGfH

petcore

Verband Metallverpackungen

Companies

PET CYCLE

Coca-Cola

DANONE

DER GRÜNE PUNKT

SIG

BMW

BAYER

Red Bull

MVV Energie

P&G

Tetra Pak

Kimberly-Clark

Organisations of Development cooperation

inWent
Internationale Weiterbildung und Entwicklung gGmbH

CDG Carl Duisberg Gesellschaft e.V.

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

GOPA WORLDWIDE CONSULTANTS

Schools, Public Services, ASEW, Consumer Advice Centre

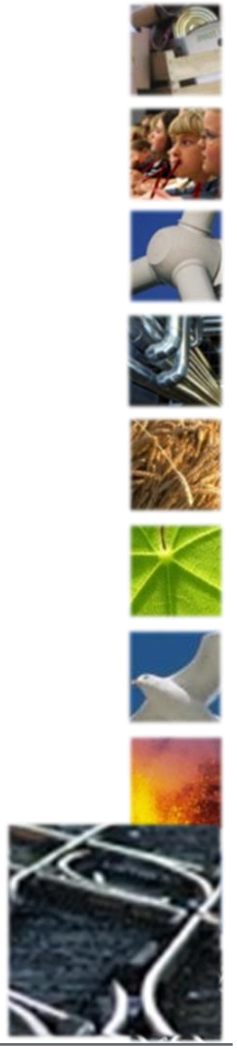
Foundations

Departments

Department	Head of Department
Nutrition and Biomass	 Guido Reinhardt, PhD, biologist, chemist, mathematician
Industry and Products	 Jürgen Giegrich MSc, physicist  Bernd Franke MSc, biologist
Transport	 Udo Lambrecht MSc, physicist
Energy	 Lothar Eisenmann MSc, physicist  Martin Pehnt Dr. Ing. PhD, physicist

Areas of Work

- Waste Management and Resource Conservation
- Environmental Education
- Energy (and Renewable Energies)
- Industry and Products
- Nutrition and Biomass
- Sustainability
- Life Cycle Assessment (LCA)
- Risk Assessment
- Environmental Impact Analysis (EIA)
- Strategic Environmental Assessment (SEA)
- Traffic and Transport
- …. and many others



Agenda.

1. National strategy on electric mobility
2. Overview on Electric/Hybrid Bus Programme
3. Evaluation Results of Electric Buses in Germany
4. Comparison of different drive train options



Timeline of Electric Mobility Policy in Germany

- National Strategy Conference Electric Mobility (2008)
- Economic Stimulus Package II (2009)
- National Electromobility Development Plan (2009)
- Joint Agency for Electric Mobility – GGEMO (2010)
- National Electric Mobility Platform (2010)
- Government Program Electromobility (2011)
- Electric Mobility Act (2014)

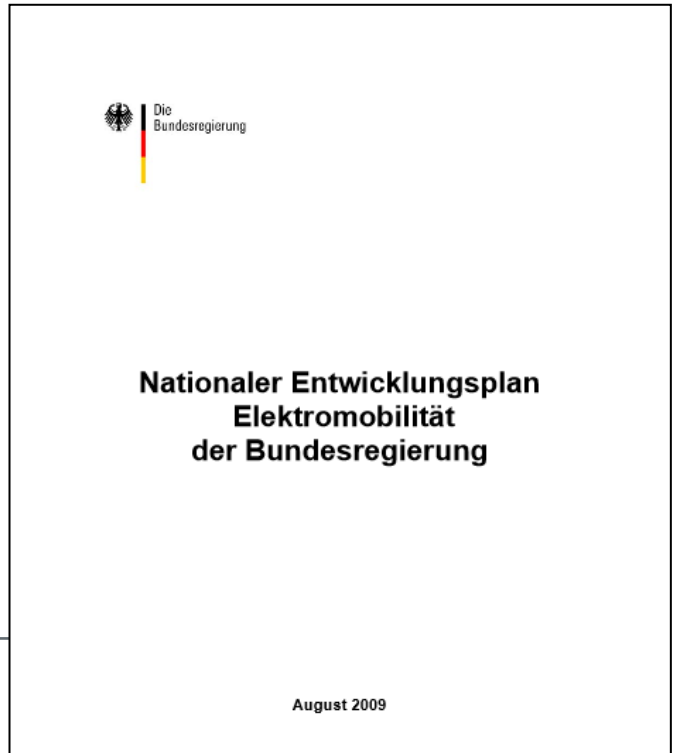
Model Regions Electromobility 2009 - 2011

- Part of the Economic Stimulus Package II
- Funding of electric mobility projects in 8 regions by the Federal Ministry of Transport and Digital Infrastructure (BMVI)
- Coordination and management by NOW GmbH (National Organisation Hydrogen and Fuel Cell Technology)

National Electromobility Development Plan

- Electromobility as part of a national strategy to become …
  - a lead market for electromobility
  - a leading supplier of electromobility
- National Development Plan Electromobility (2009)
  - Goal of 1 Million vehicles until 2020
  - Goal of 6 Million vehicles until 2030

(For comparison:
Currently 44 Million passenger cars registered in Germany)



National Platform for Electric Mobility

- Founded May 2010 and reports to the Federal Government
- Brings together stakeholders from industry, science, politics, trade unions and associations for a strategic dialogue
- Observes and analyses the development in the field of electro mobility
- Seven Working Groups with about 20 representatives develop measures and recommendations for electro mobility:
  - Drive train technology
  - Battery technology
  - Charging infrastructure and grid integration
  - Standardisation and certification
  - Materials and recycling
  - Education and training
  - Framework conditions

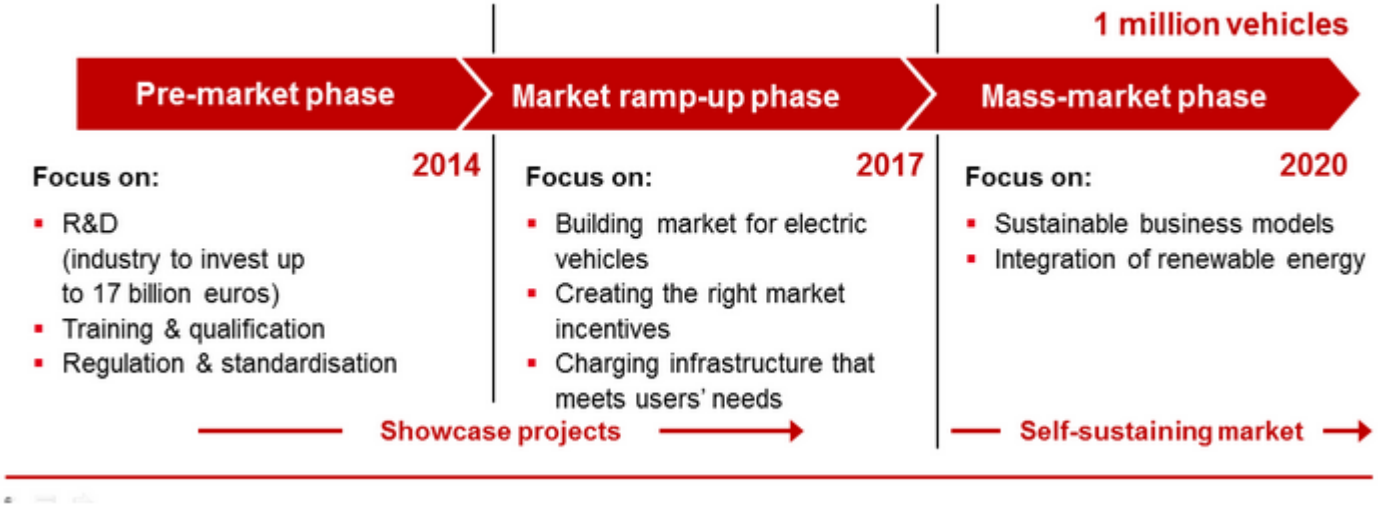
National Platform for Electric Mobility

- Supported by the Joint Agency for Electric Mobility (Gemeinsamen Geschäftsstelle Elektromobilität (GGEMO))
- Collaboration of four ministries:

  - Federal Ministry for Economic Affairs and Energy
  - Federal Ministry of Transport and Digital Infrastructure
  - Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
  - Federal Ministry of Education and Research

National Platform: The approach

- Systemic from the users' point of view
- Open technology, covering battery electric vehicles (BEV) but also plug-in hybrids (PHEV) and range extenders (REEV)
- Market oriented

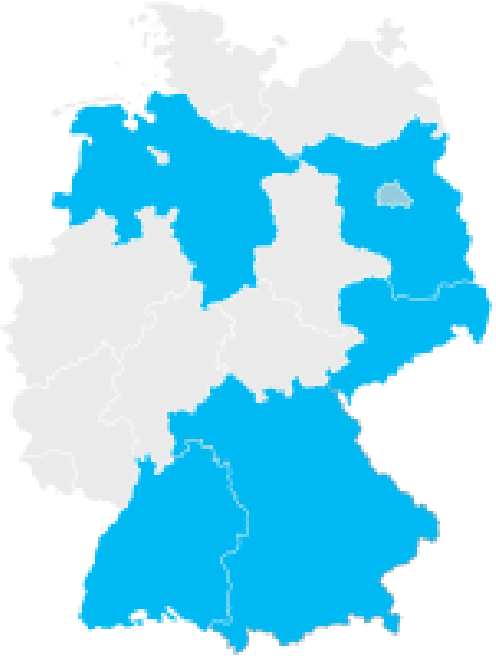


Discussed measures

- Introducing a special depreciation of 50% in the first year for commercial users because fleets and company cars are seen as a gateway to electric mobility
- Strengthening investment partnerships between the public and private sectors to develop publicly accessible charging infrastructure
- Implementing the EU directive on alternative fuels including the expansion of the charging infrastructure
- Implementing public and private initiatives to integrate electric vehicles in fleets
- Continuing research and development with Federal Government support
- Promoting the establishment of a long-term cell manufacturing facility in Germany

Showcase Program 2012-2015

- Living Lab BW E-Mobil (Baden-Württemberg)
- International Showcase of Electromobility (Berlin / Brandenburg)
- Our horse powers becomes electric (Lower Saxony)
- Electromobility connects (Bavaria / Saxony)



German E-Mobility Law (EmoG)

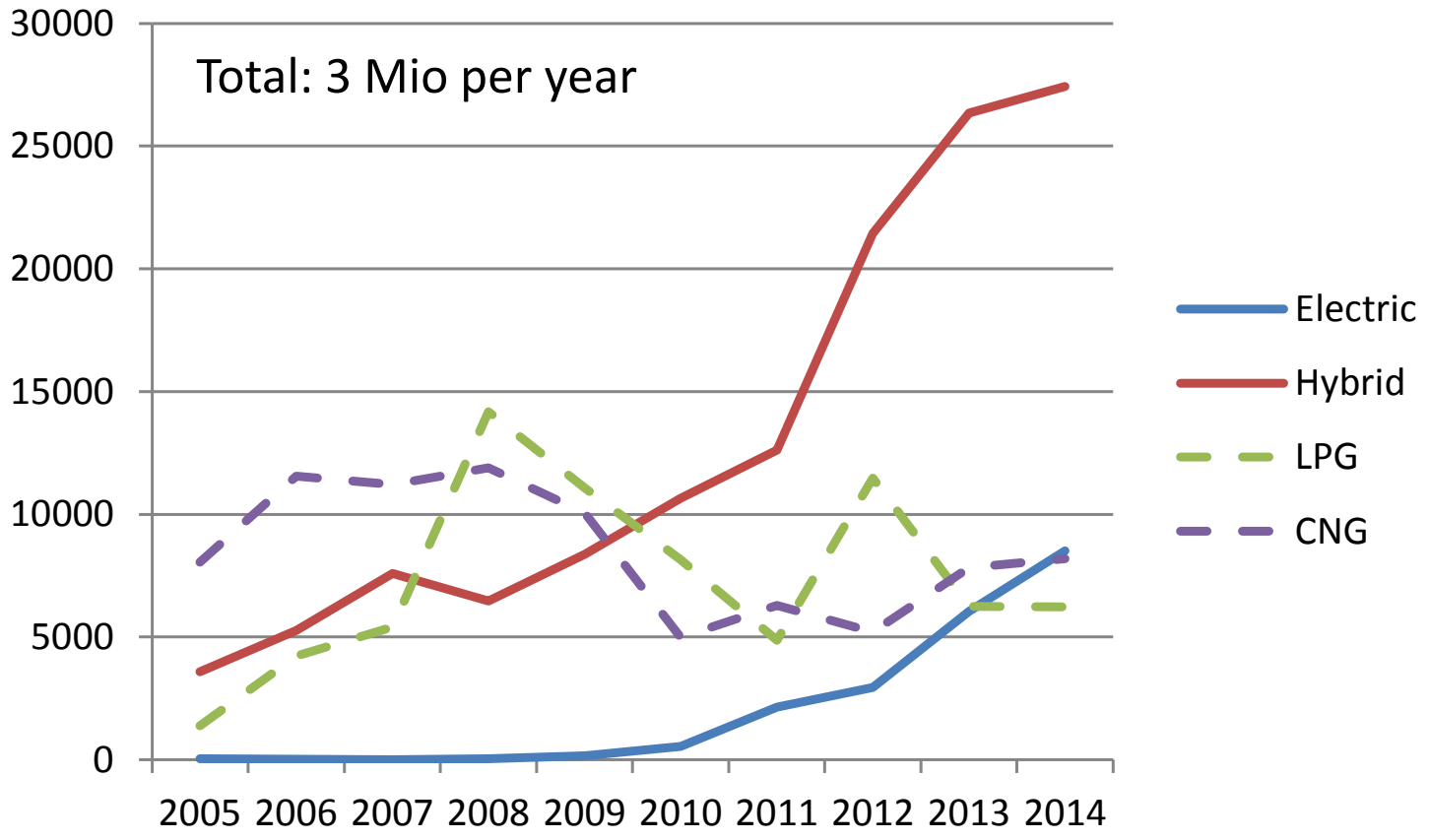
Effective from June 2015

Enables municipality for privilege electric vehicles

- Definition of privileged vehicles
- Implements Labelling on licence plate
- Enables privileges for parking
- Enables use of bus lanes
- Enables access to restricted areas

New registrations of alternative drive trains

- New registrations rising, but still limited



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Drivers for Electrification of Buses

- Reduction of (fossil) energy consumption
- Reduction of GHG-Emissions
- Integration of renewable energy
- Integration of new technologies (Batteries, Ultra-Caps, Fast-Chargers)
- Rising oil prices
- Emissions of air pollutants
- Noise

Overview of electric bus program

- Funding by
  - Federal Ministry for Economic Affairs and Energy
  - Federal Ministry of Transport and Digital Infrastructure
  - Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
- Subsidies for market penetration of hybrid (diesel-electric) buses
- Pilot projects for electric buses

Funding for Hybrid Bus

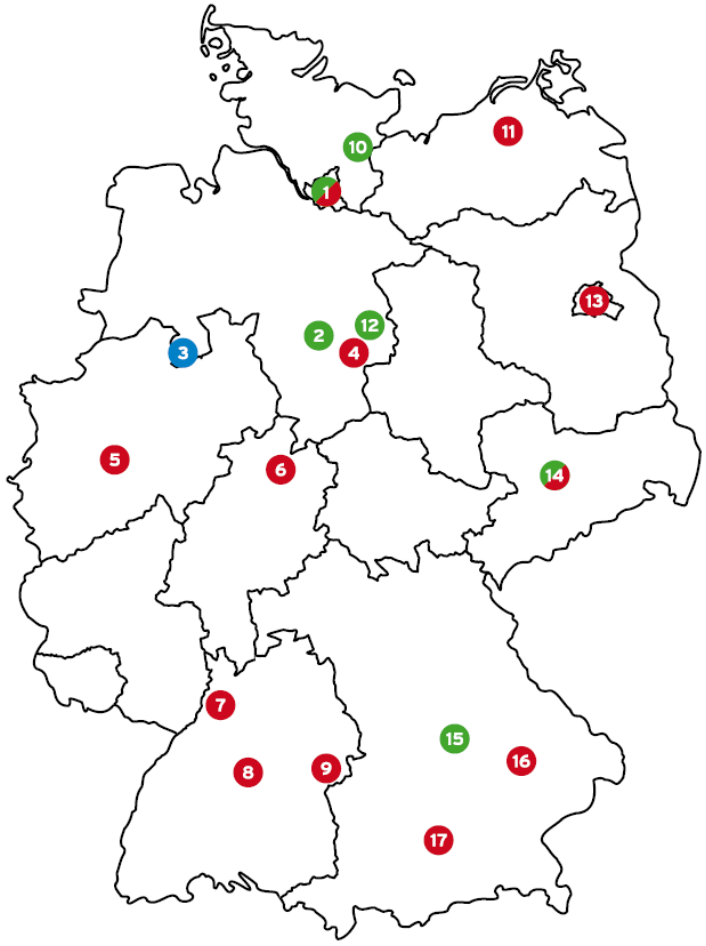
- Since 2012 as part of the National Climate Protection Initative (NKI) of the Ministry for the Environment (BMUB)
- 60 Hybrid buses funded in 6 transport companies over the last two years
- Extended until 2017
  - Up 35% of additional costs for Plug-In Hybrids
  - For conventional hybrid limited for vehicle costs at 100.000 € for solo and 200.000 € for articulated buses

Pilot projects with alternative buses in Germany

29	projects
34	companies
171	diesel hybrid buses
86	solo buses
85	articulated buses
25	electric buses
12	Fuel cell buses

Supporting ministries:

- BMVI
- BMUB
- BMWi



Source: [AG Innovative Antriebe Bus 2015]

A closer look at selected bus projects …

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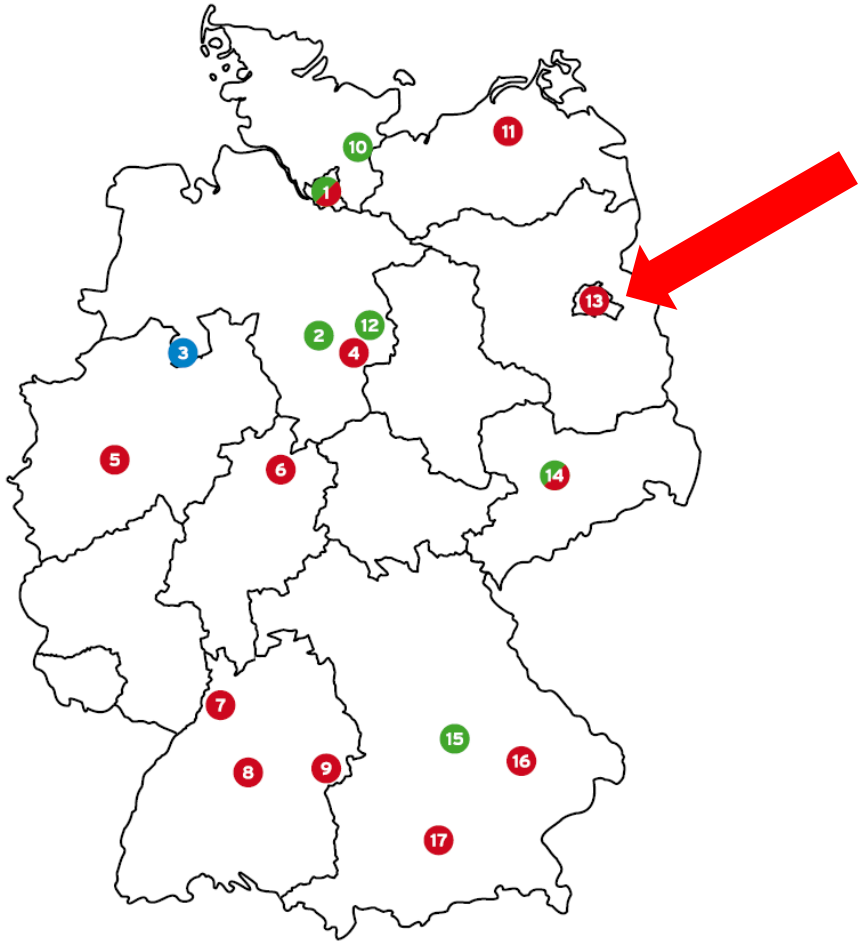


Source: [AG Innovative Antriebe Bus 2015]

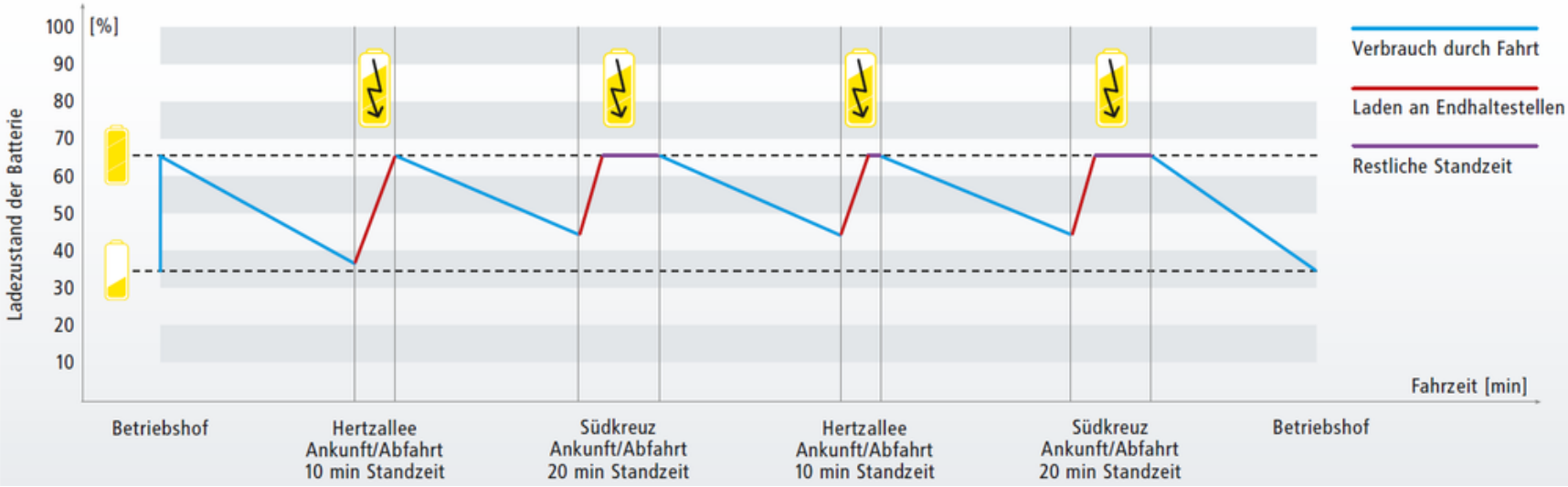
Berlin: E-Bus Berlin

- Four vehicles on Line 204
- Urbino 12 Electric from Solaris
  - 90 kWh Li-Ion-Battery
  - Battery weight 1,1 Tonne
  - 70 passenger capacity
  - 160 kW electric engine

Source: http://e-bus.berlin/

Berlin: E-Bus Berlin

- Inductive fast charging with 200 kW (4-7 Minutes)
- Charging system Primove of Bombardier
- Concept opportunity charging at terminal stops



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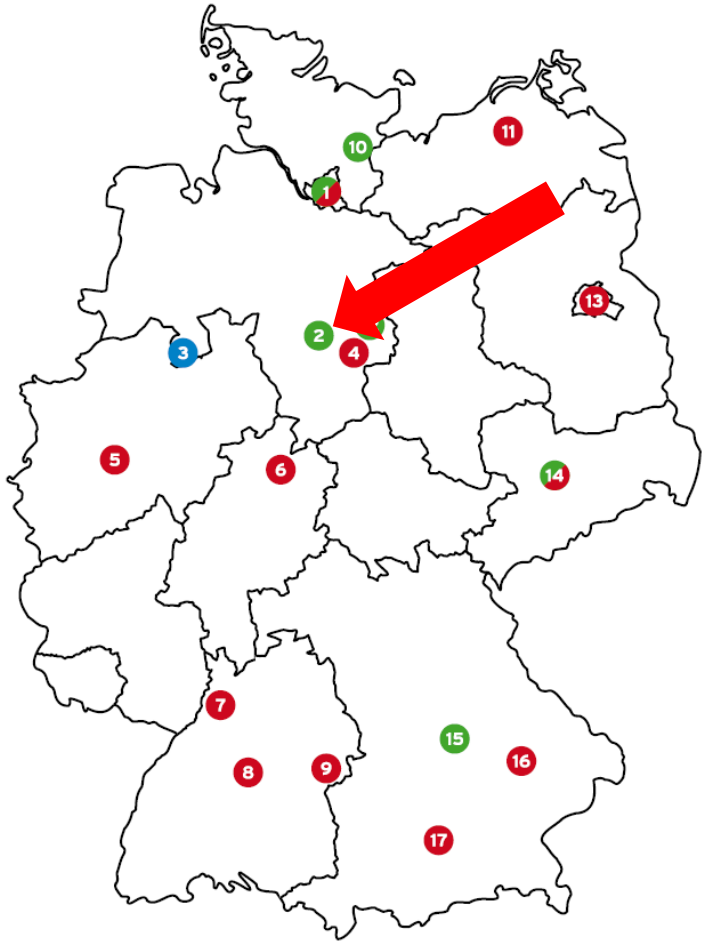
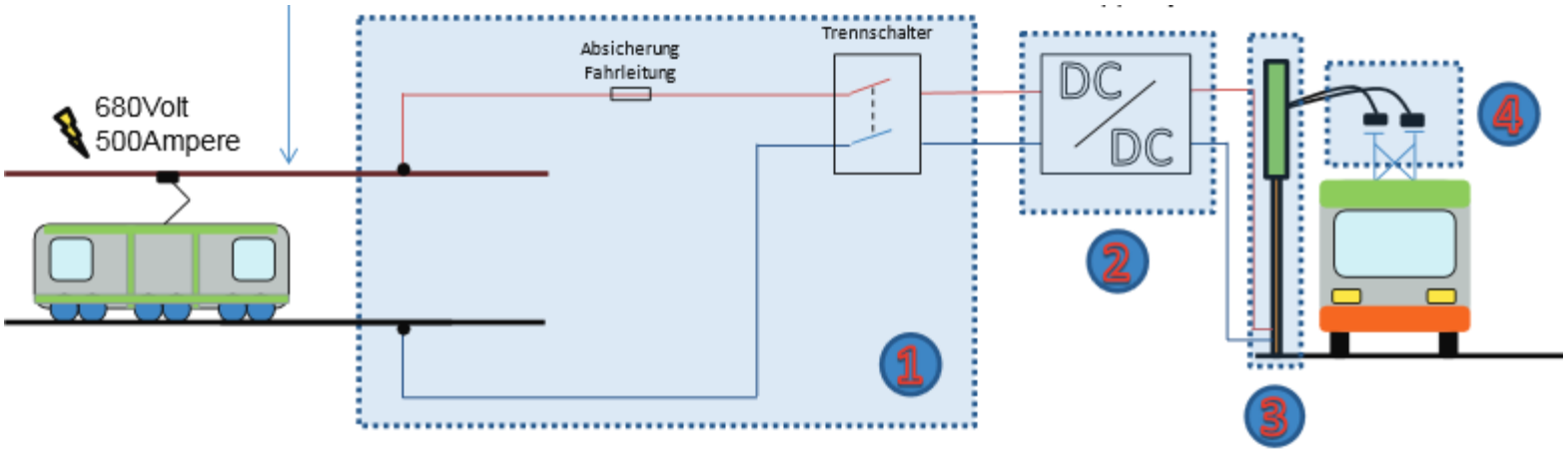


Source: [AG Innovative Antriebe Bus 2015]

Hannover: Emission free local traffic Hannover

- Test of 3 Electric buses (Solo)
- 140-160 kWh Battery pack
- Circular Line 100/200 (only 1 terminal stop)
- 16 km total length, 10 Minute daytime frequency
- Recharging from tram catenary lines (6 Min. for 25 kWh)



Source: http://www.erneuerbar-mobil.de/

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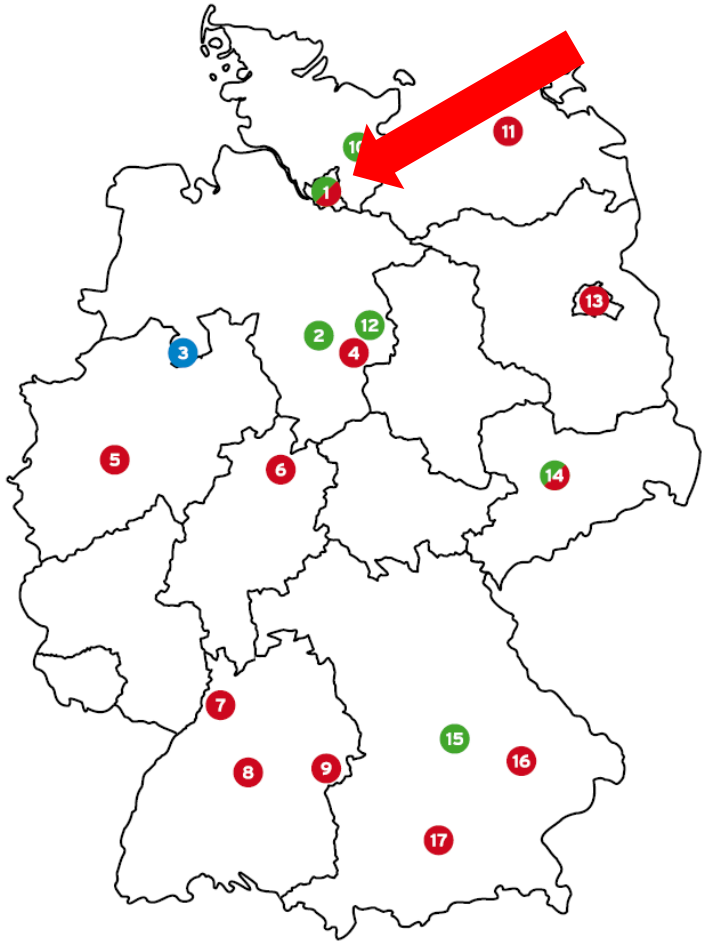

Source: [AG Innovative Antriebe Bus 2015]

Hamburg: HELD

HELD: Hamburg Electric Bus Demonstration

- 3 PlugIn Hybrids and 3 Electric Buses until 2017
- Line 109 over 10 km in inner city
- Opportunity charging at terminal stops
- Fast charging with up 300 kW
- Pantograph connection

Source: http://www.erneuerbar-mobil.de/

Hamburg: Blankenese

- Rampini Solo-Bus with Siemens Engine (12 m)
- 180 kWh LFP-Battery (100 km Range)
- 5,2 km route on Line 48 in HH-Blankenese (18 Minutes = as for Diesel)
- Steep road up to 16% grad
- Conductive nighttime charging depot and short recharging periods at terminal stop (20 Minutes)

Source: http://griin.de/mobilitaetskonzepte/erster-elektro-bus-in-hamburg-blankenese

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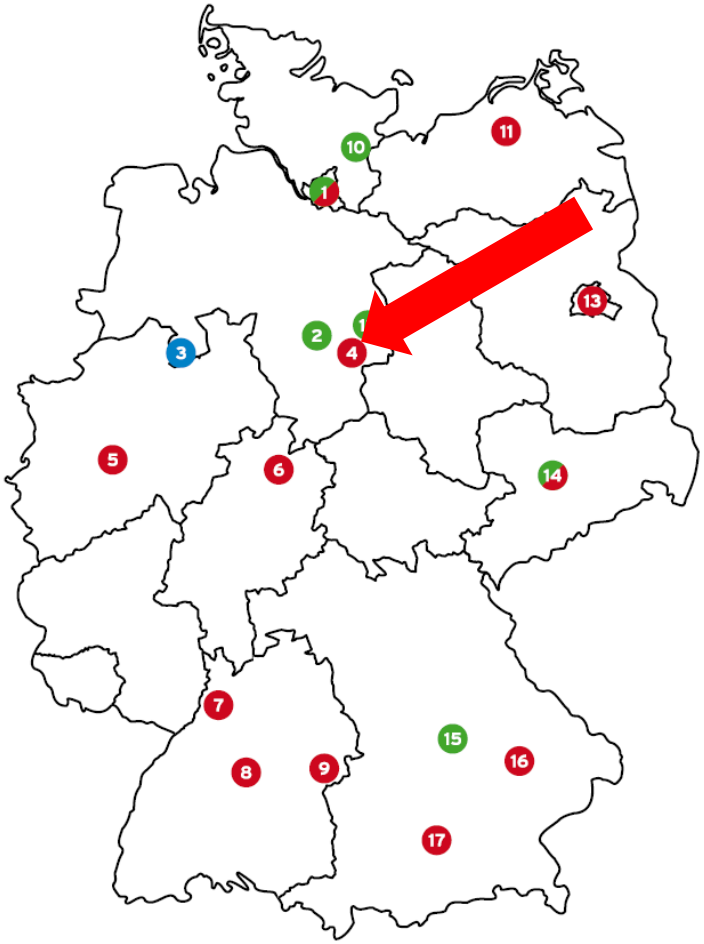

Source: [AG Innovative Antriebe Bus 2015]

Braunschweig: emil (Showcase project)

- Test of 4 Solaris Electric Buses since 2014 on Line M19
  - 1 x 12 m Solo Bus (60 kWh Primove Battery)
  - 4 x 18 m Articulated Bus (90 kWh Primove Battery)
- Primove Inductive Charging System (> 90 % Efficiency)
- Fast charging with 200 kW

 source: http://www.verkehr-bs.de/unternehmen/forschungsprojekt-emil/elektrobus.html

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Evaluation by Working Group Innovative Powertrains Bus

Composition of the Working Group:

- 25 Transport Companies
- Industry representatives (10 manufacturer and supplier of innovative city buses)
- Association of German Transport Companies (VDV)
- Representatives of Transport Associations
- 8 Organisations from science and consulting

Evaluation data and categories

Evaluation based on

a. Continous web based data collection

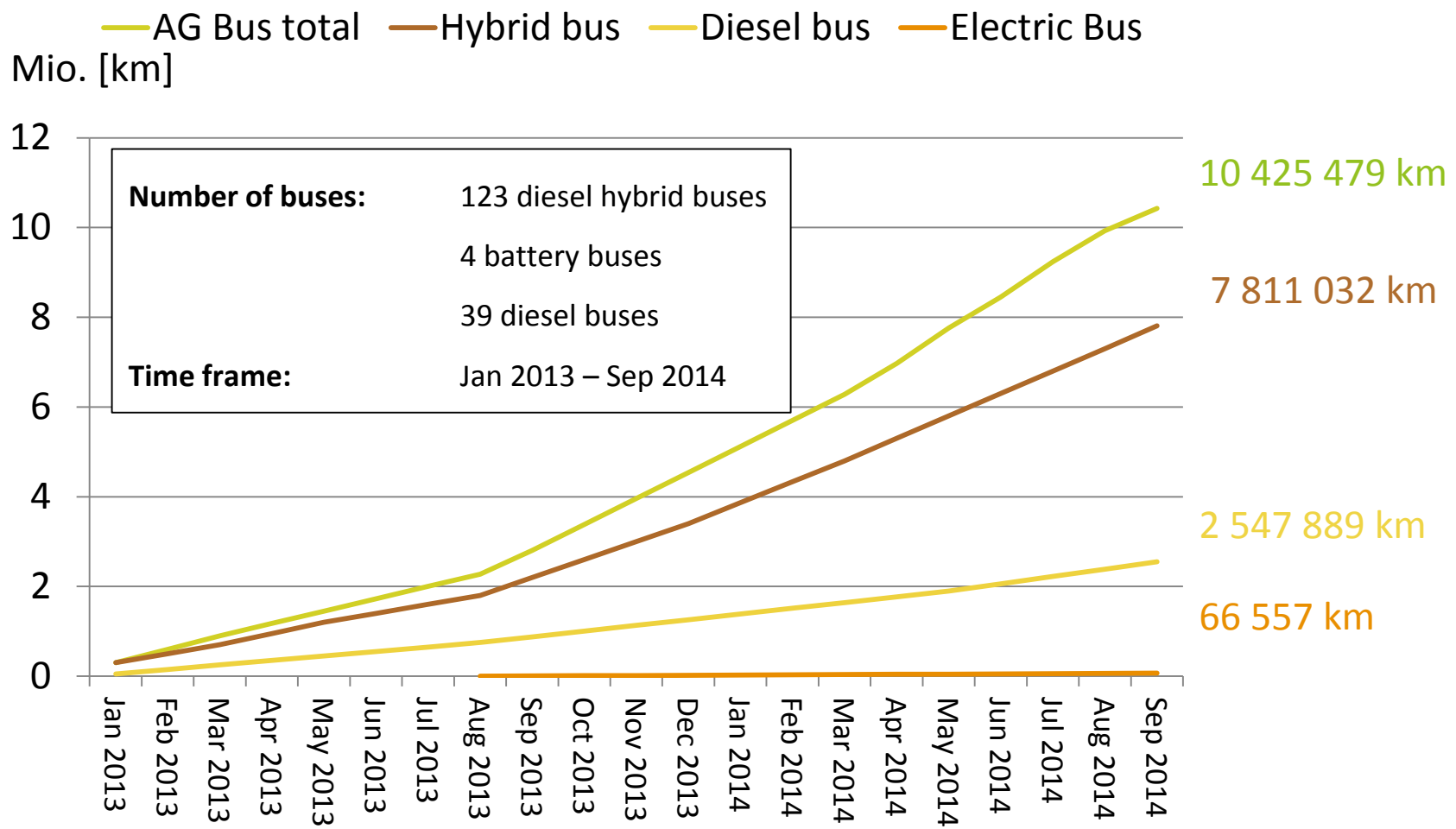
b. Single emission measurements

Evaluation categories

- **Road capability**
- **Energy efficiency**
- **Emission/GHG Reduction**
- **Cost effectiveness**
- **Acceptance**

Source: own representation based on [AG innovative Antriebe Bus 2015]

Total mileage evaluated so far …



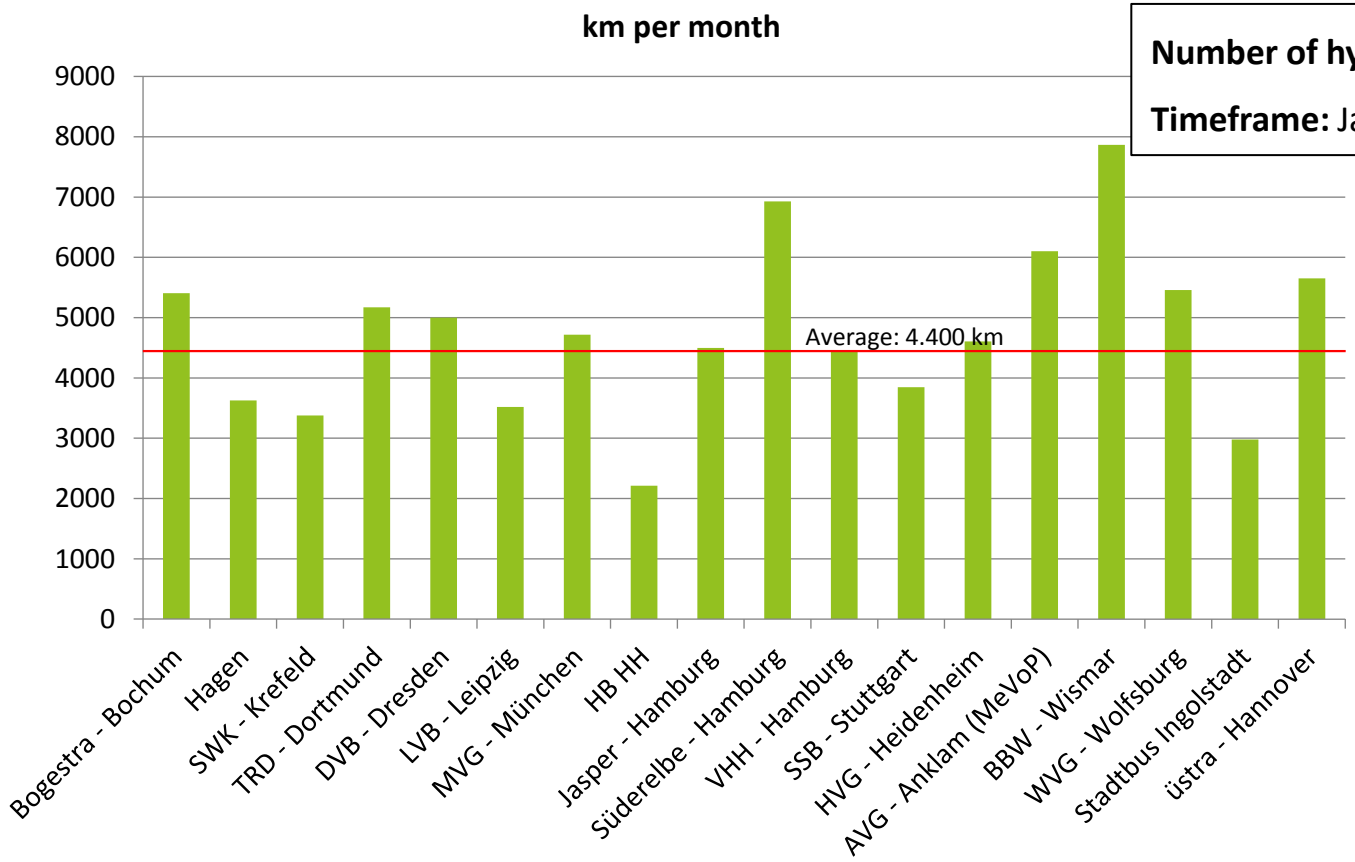
Source: own representation based on [AG innovative Antriebe Bus 2015]

Total mileage evaluated so far …

- **Daily operation data of more than 10 Million km have been collected since 2013**
- **Good data base for hybrid and diesel buses**
- **Fewer data for electric buses included so far, because…**
  - … only 4 electric buses have been evaluated so far
  - … electric buses have a lower monthly performance (daily range of electric buses limits the monthly mileage)
- **But more electric buses are currently being operated …**
  … more data to be expected

Monthly performance of hybrid buses …

Monthly performance of hybrid buses ranges from 2200 km to 7900 km depending on the company



Number of hybrid buses: 123

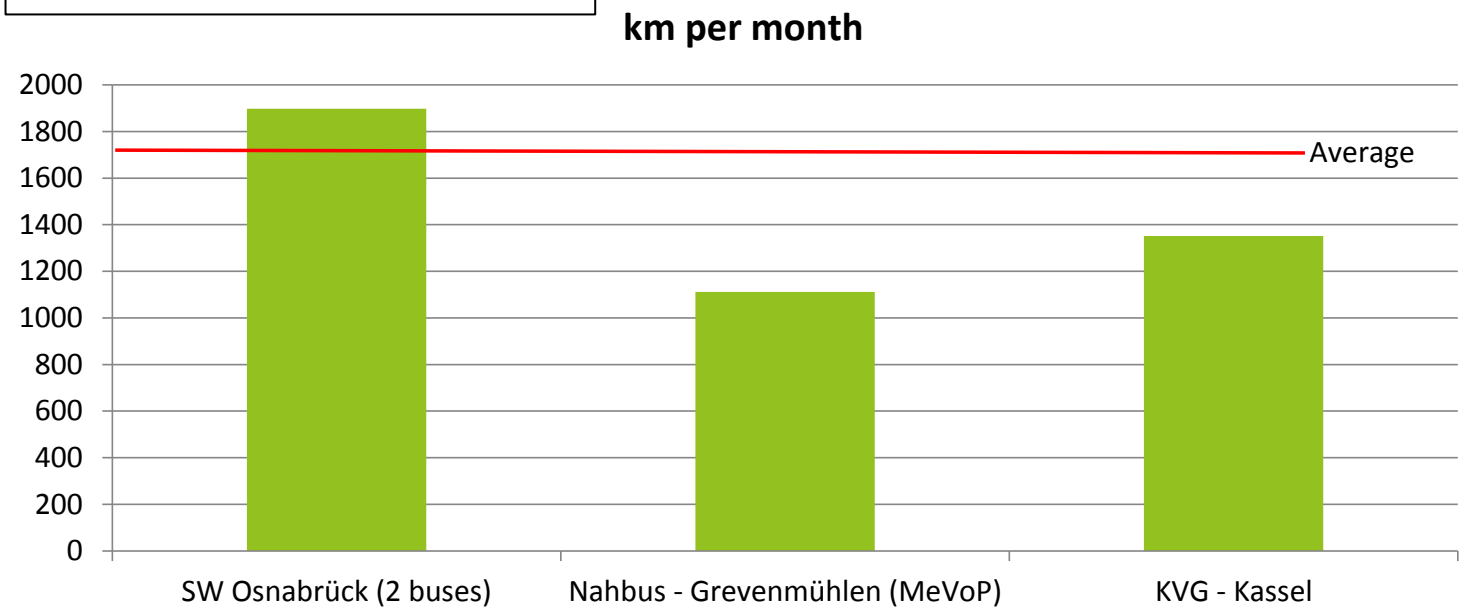
Timeframe: Jan 2013 – Sep 2014

Source: own representation based on [AG innovative Antriebe Bus 2015]

… and monthly performance of battery buses

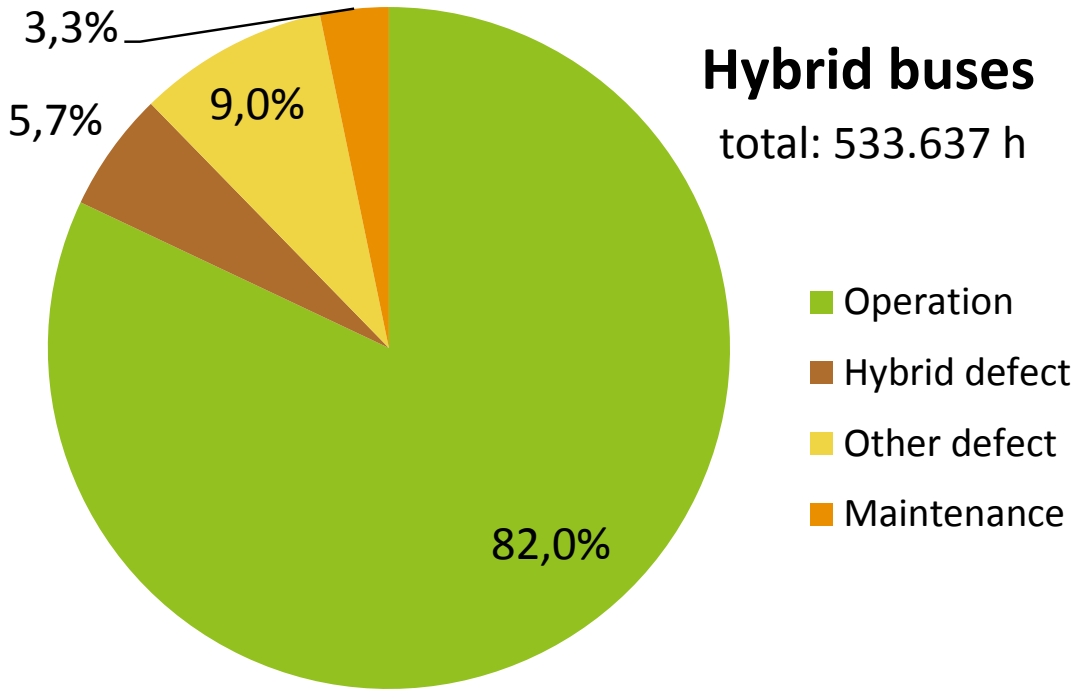
Number of electric buses: 4

Time frame: Jan 2013 – Sep 2014



Source: own representation based on [AG innovative Antriebe Bus 2015

Hybrid buses: availability and defects

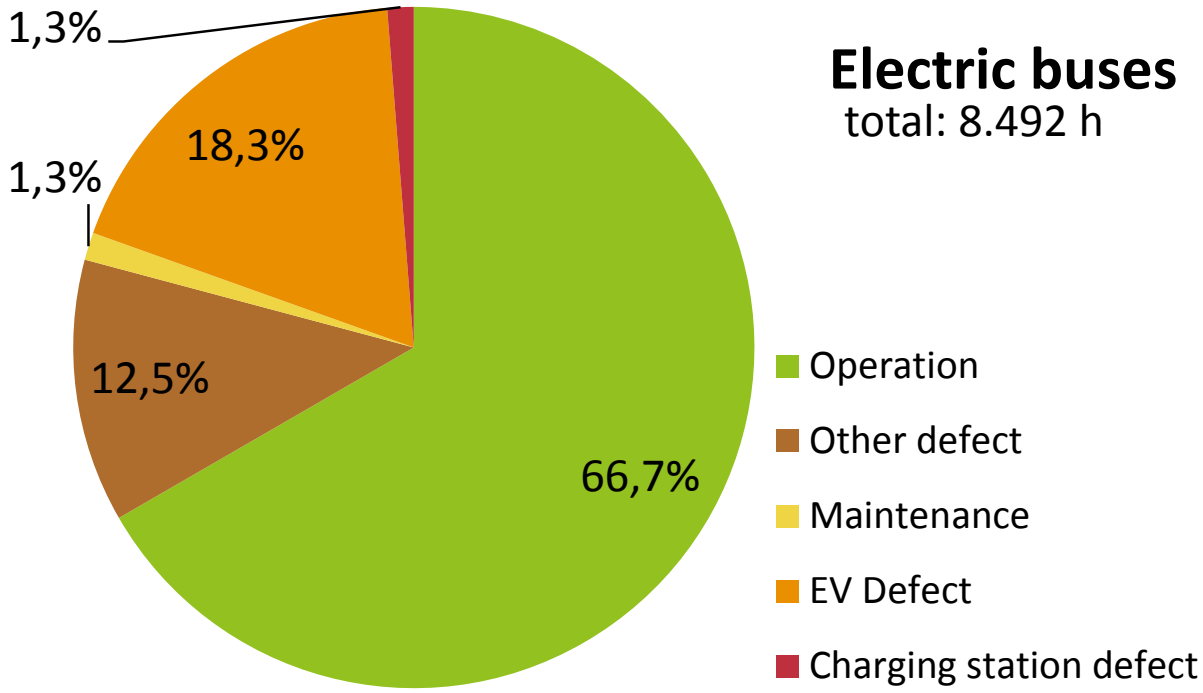


Number of hybrid buses: 111

Space of time: Jan 2013 – Sep 2014

Source: own representation based on [AG innovative Antriebe Bus 2015

Electric buses: availability and defects



Number of electric buses: 4

Space of time: Jan 2013 – Sep 2014

Source: own representation based on [AG innovative Antriebe Bus 2015

Availability Overview

Hybrid buses:

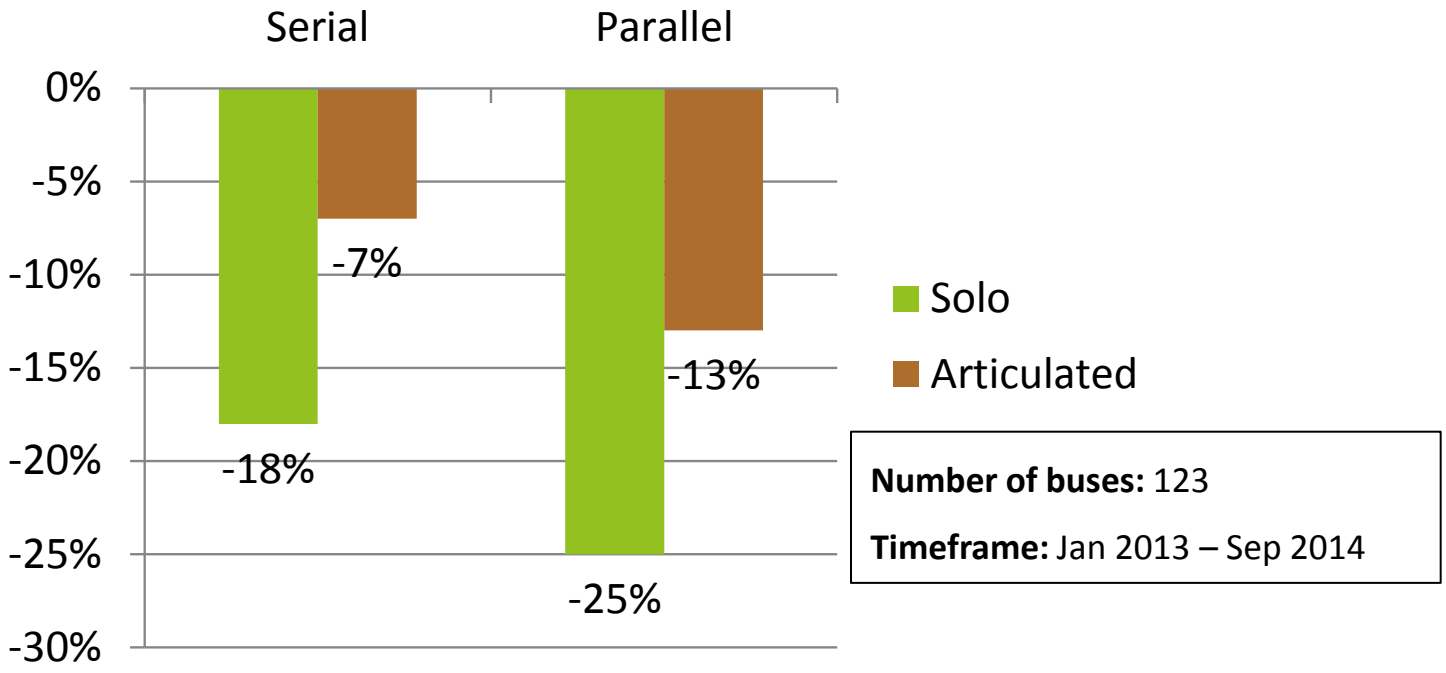
- Availability of 82 %
- Hybrid specific defects caused failures of 6 % of operating hours (other defects 9 %)
- The percentage of maintenance is comparable to conventional buses

Electric buses:

- Availability of 67 %
- The small quantity (only 4 buses) stresses one-time incidents
- Two of the four buses have an availability of about 80 %
- Development of availability shows an increasing learning curve during the survey

Fuel savings of hybrid buses compared to diesel

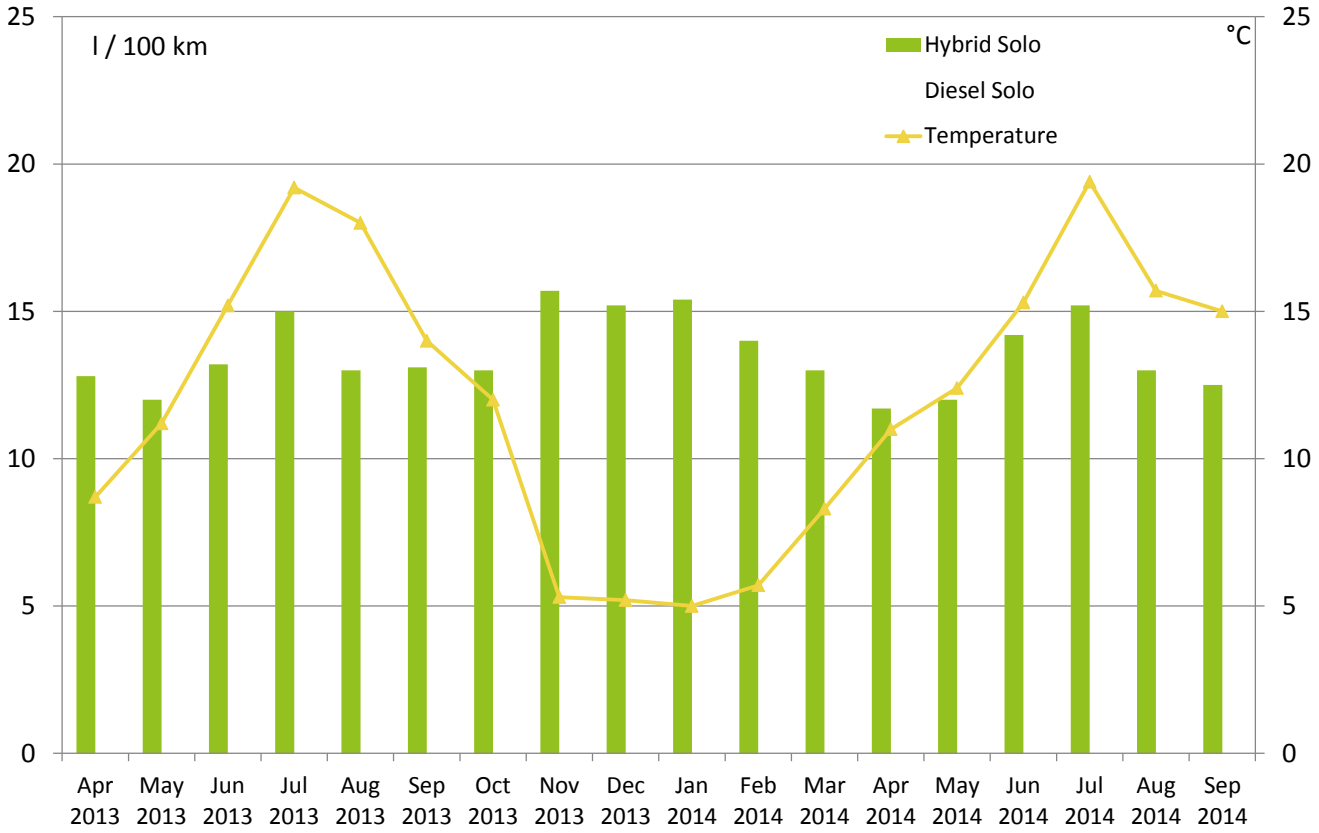
Parallel buses have higher savings compared to serial buses



Source: own representation based on [AG innovative Antriebe Bus 2015

Correlation of fuel consumption to temperature

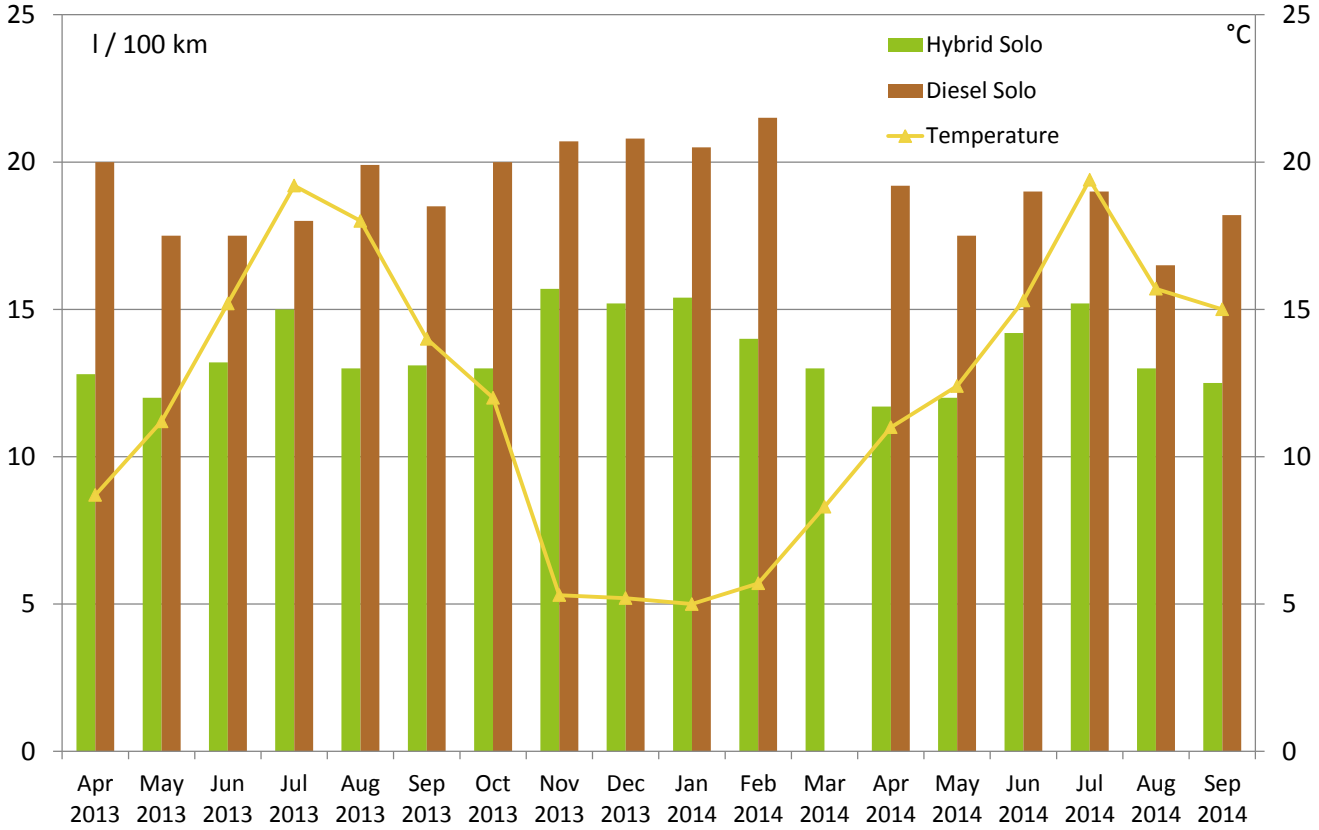
Hybrid buses has heating and cooling!



Source: own representation based on [AG innovative Antriebe Bus 2015

Correlation of fuel consumption to temperature

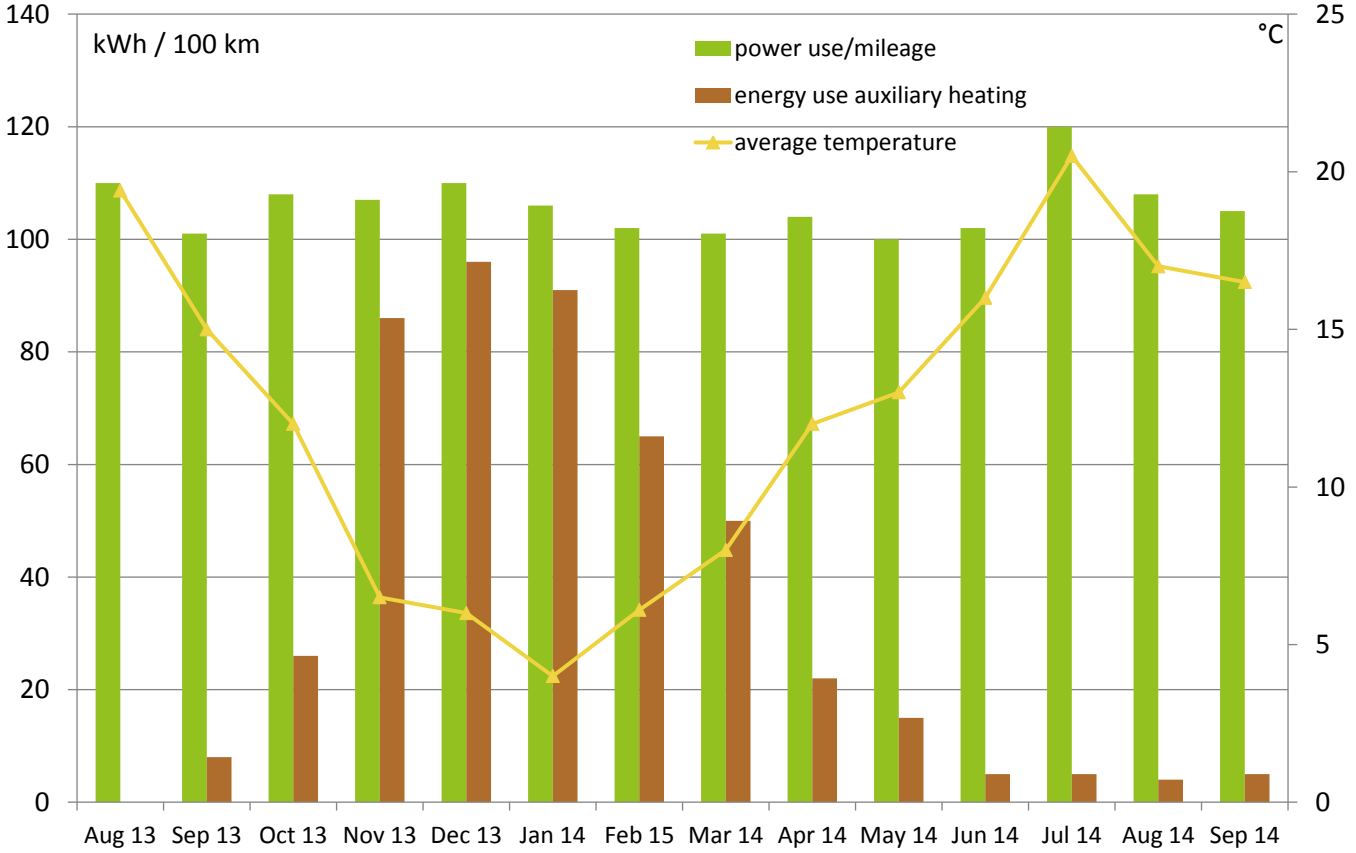
Diesel bus only with heating, but no air conditioning!



Source: own representation based on [AG innovative Antriebe Bus 2015

Electric bus consumption for heating

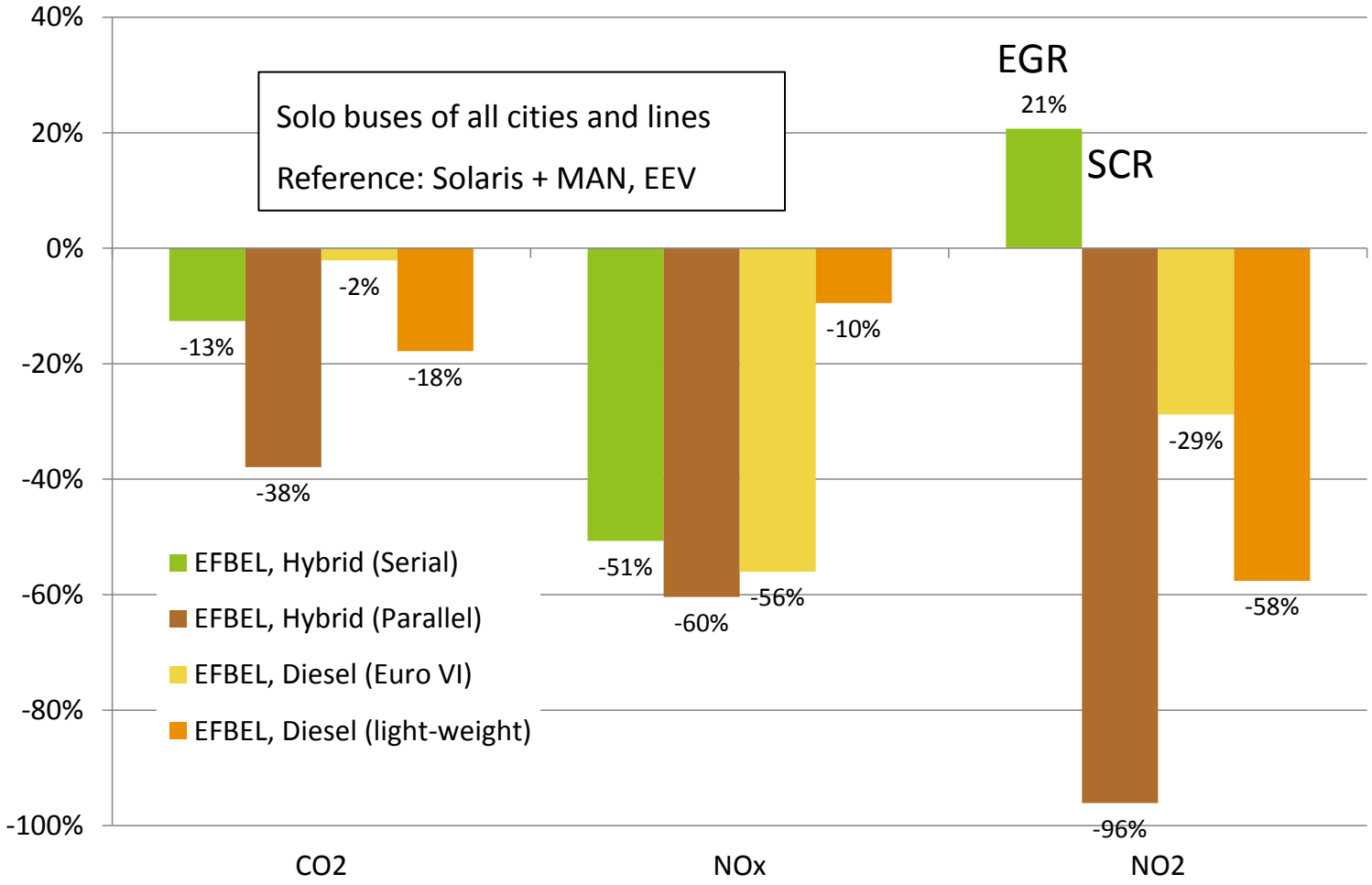
Heating consumption can be as propulsion consumption



Source: own representation based on [AG innovative Antriebe Bus 2015

Emission behaviour of hybrid solo buses

compared to conventional diesel bus – Euro V EEV



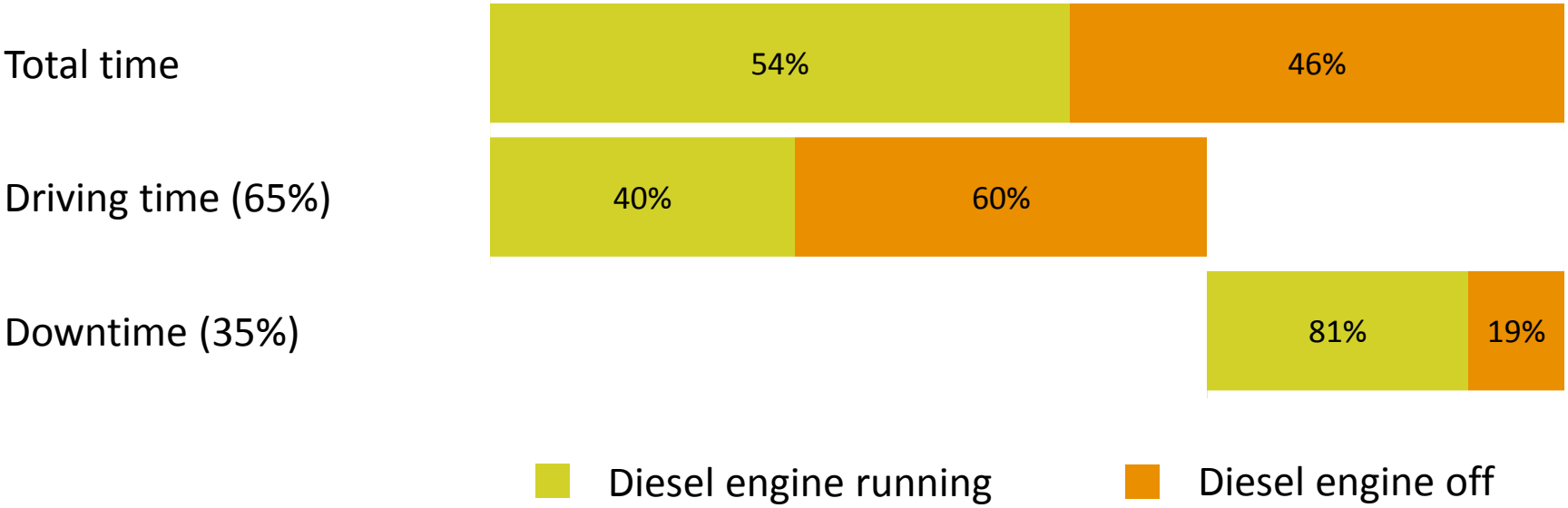
Source: own representation based on [AG innovative Antriebe Bus 2015 0

Running time of the diesel engine

LFP-Battery with 27 kWh

Space of time: 01.01.2013 – 01.12.2013

Vehicles: 5 articulated serial-hybrid SSB



In Stuttgart regenerative breaking 80 kWh/100km (36% of total energy)

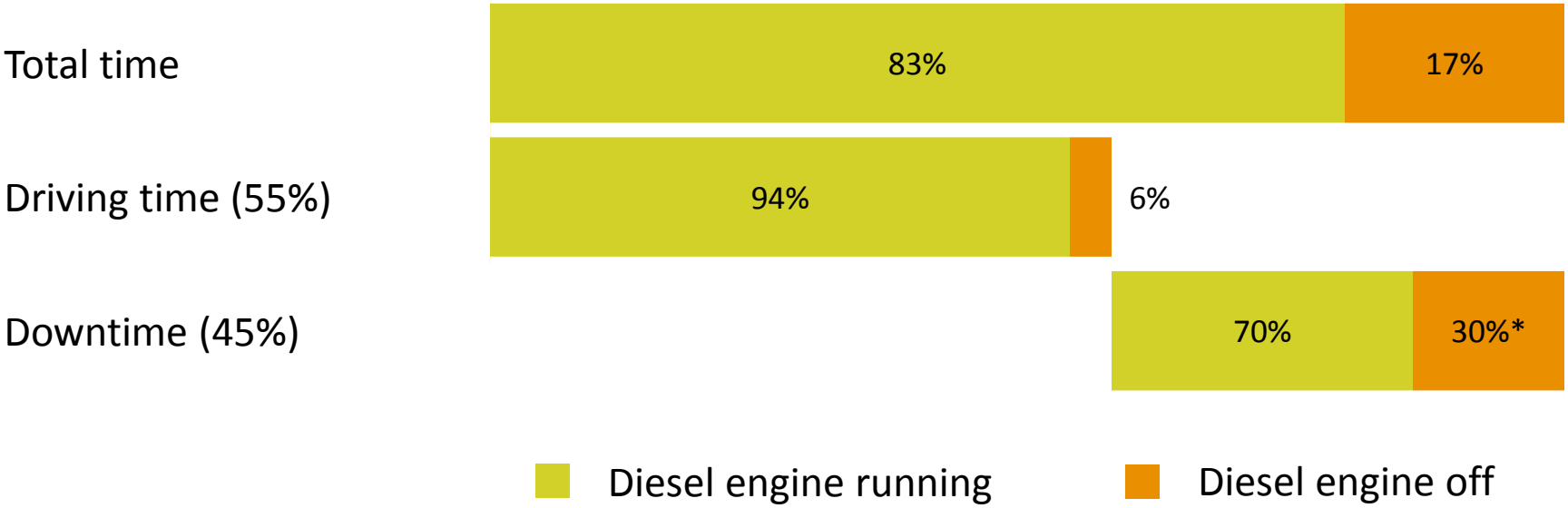
Source: own representation based on [AG innovative Antriebe Bus 2015

Running time of the diesel engine

LFP-Battery with 4,8 kWh

Space of time: 01.03.2014 – 31.10.2014

Vehicles: 7 Solo parallel-hybrid VHH

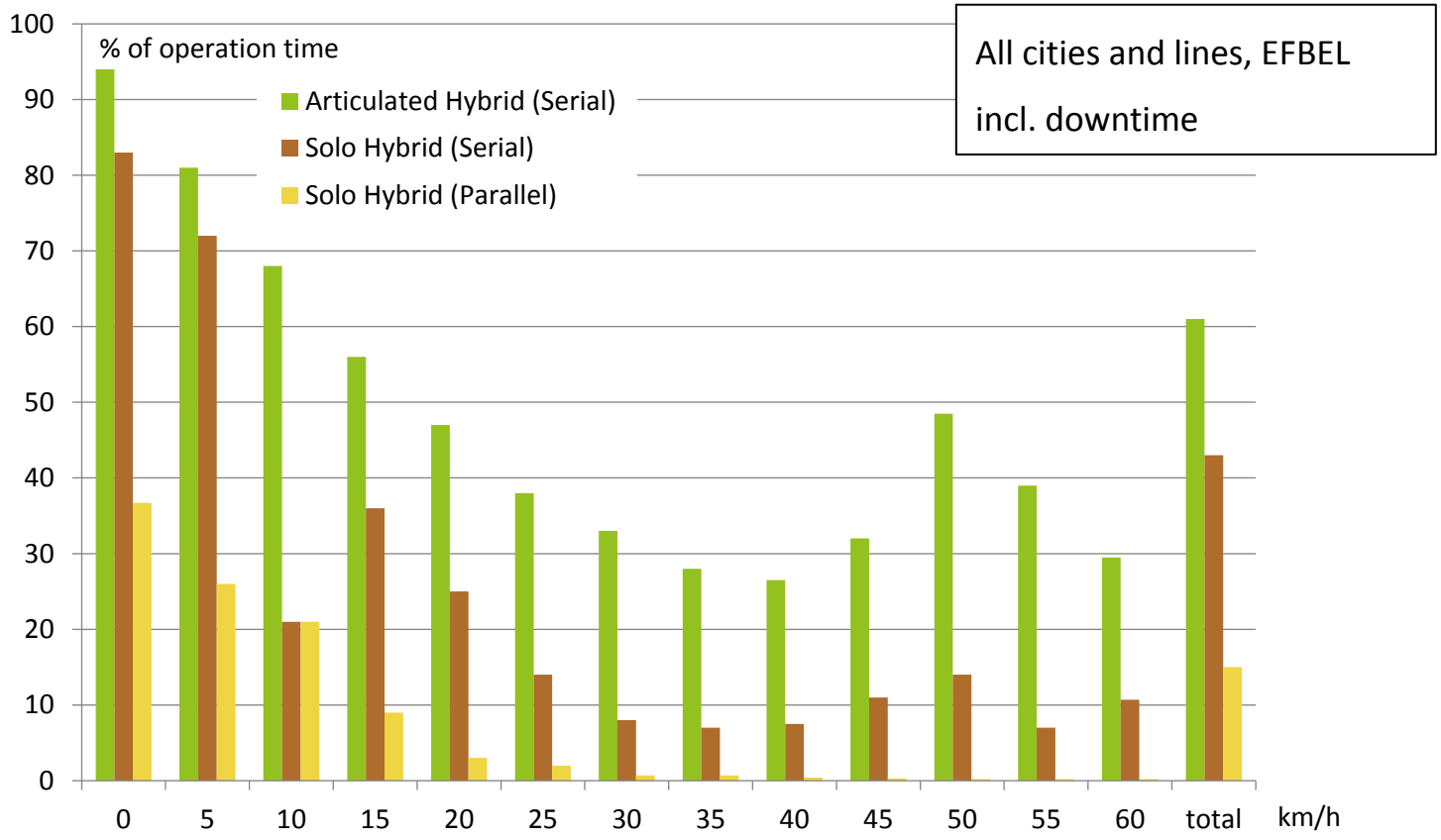


* estimated

Source: own representation based on [AG innovative Antriebe Bus 2015

Share of electric driving (hybrid buses)

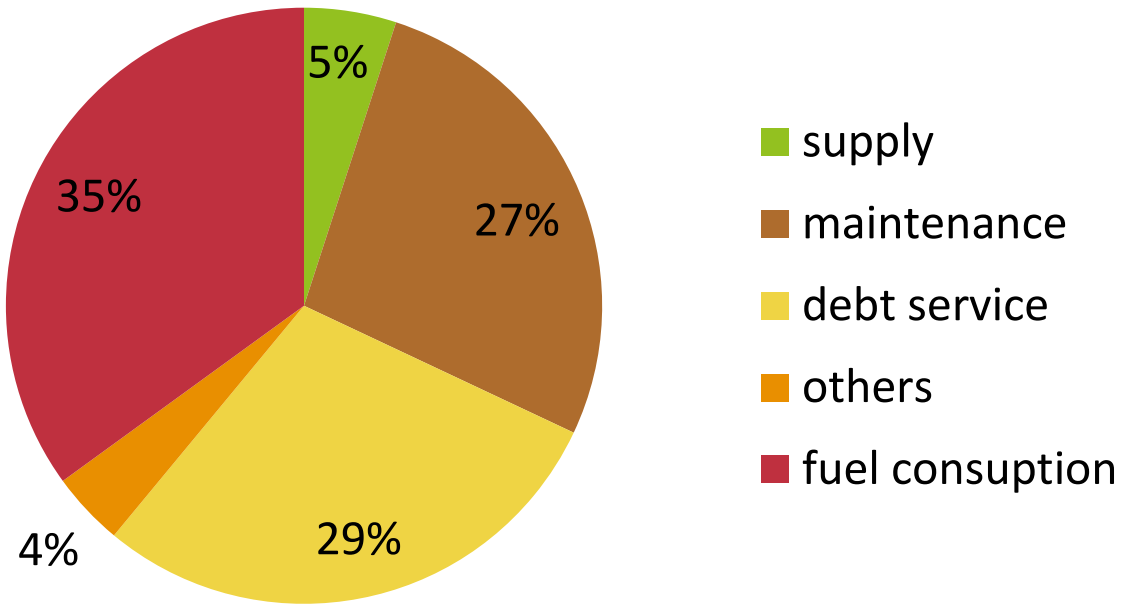
Decrease with speed



Source: own representation based on [AG innovative Antriebe Bus 2015

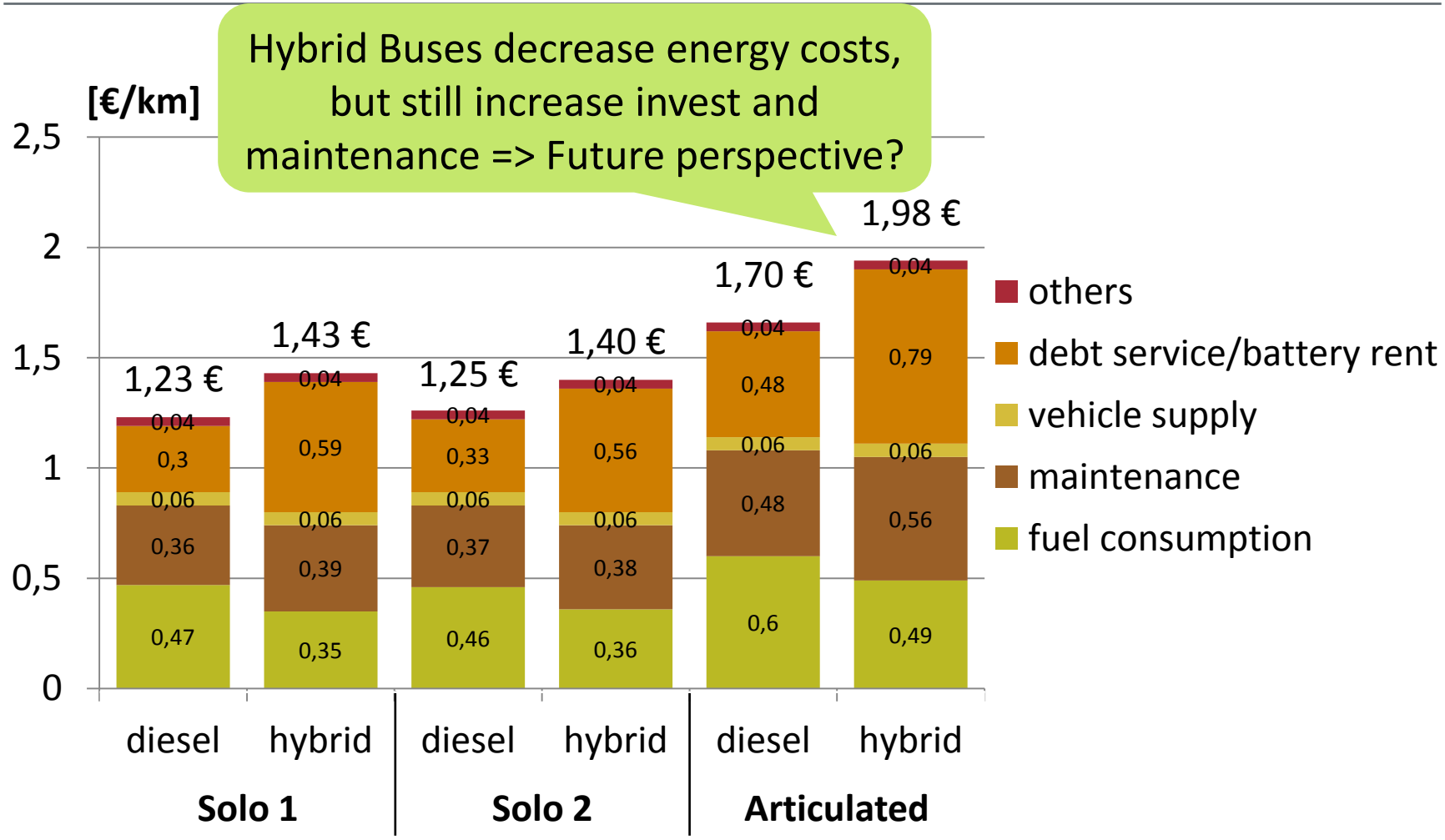
Cost situation: Conventional Diesel Bus

Total costs today dominated by fuel consumption, invest and maintenance



Source: own representation based on [AG innovative Antriebe Bus 2015

Total costs of hybrid and reference bus



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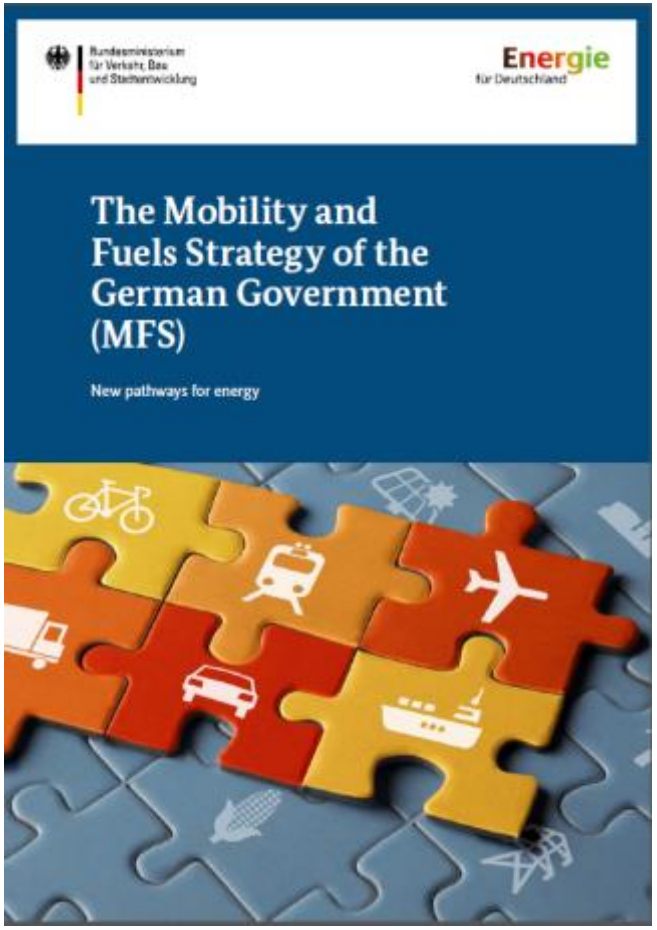
Mobility and Fuels Strategy (MFS)

What is the MFS?

- Initiated by the German Ministry of Transport (BMVI) in 2011
- Development of a „learning strategy“ including all modes
- Technology-open
- Focusing on mid and long-term solutions
- Participation of stakeholders from politics, economy, science
- Publication of scientific studies on different topics

Goals:

- Reduction of (fossil) energy consumption
- Reduction of GHG-Emissions
- Integration of renewable energy
- Integration of new technologies and mobility concepts



 Soruce picture: BMVI

Comparative Study on Bus Power trains

- Bus power trains in public transport compared
  - Overview on use worldwide and in Germany
  - Energy and environmental assessment compared to diesel
  - Cost situation in Germany compared to diesel
- Comparison of the situation today and the future perspective

Comparison of different fuel concepts

Object of comparison

- Articulated Buses
- Concepts:
  - Diesel-Euro VI (Hybrid assumed from 2020)
  - Overnight-Charger
  - Opportunity-Charger
  - Trolley-Hybrid
  - Fuel-Cell-Hybrid

Criteria:

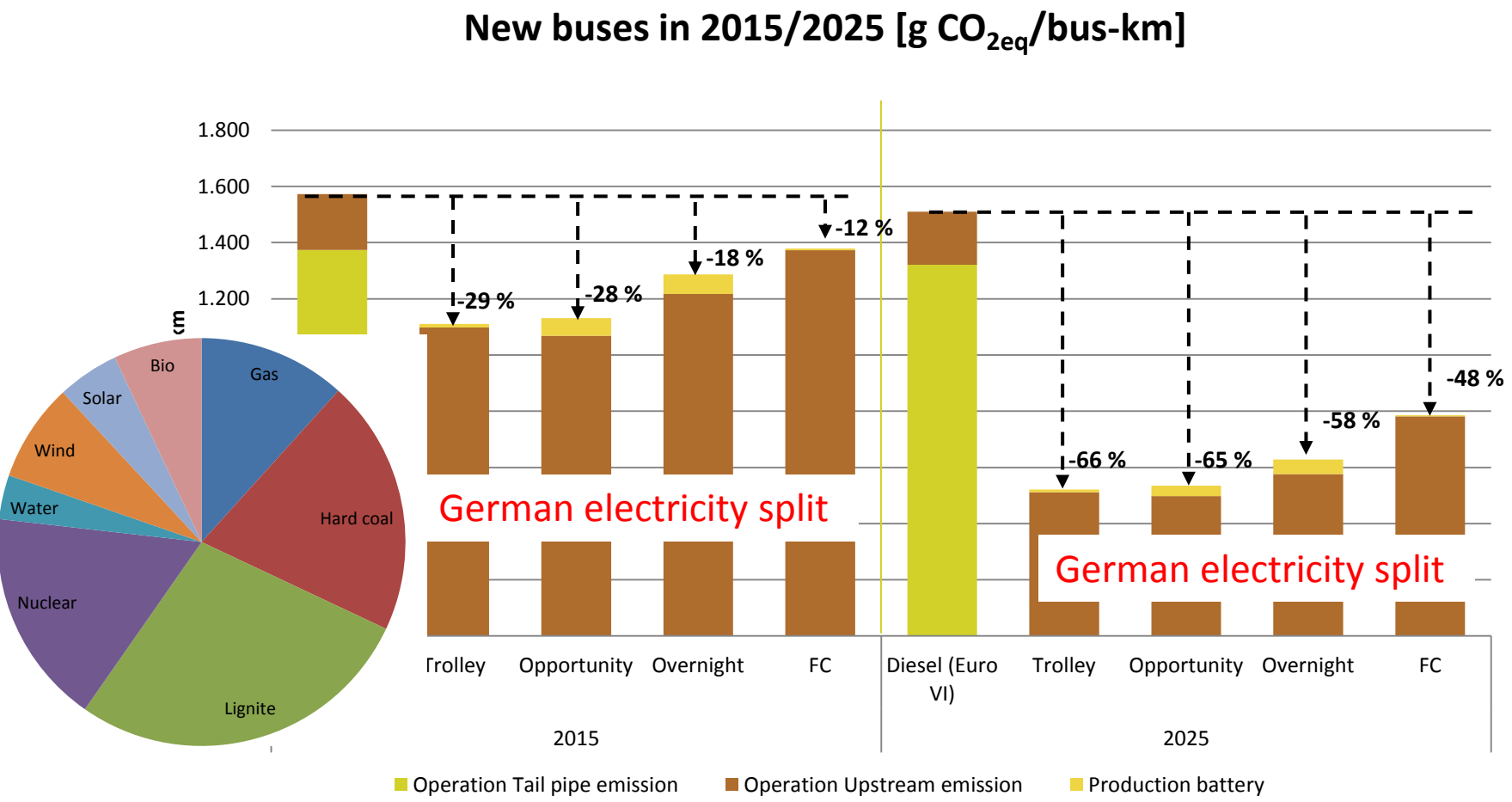
- Emissions (GHG, criteria)
- Costs
  - Vehicles
  - Operation (Energy)
  - Infrastructure
- Operational Requirements (minimal constraints for the schedule, flexibility)

Comparison of different fuel concepts – technical specifications

Variante	Infrastructure	Vehicle		
	Energy supply	Energy storage	Energy converter	Power train
Dieselbus EURO VI (Hybrid assumed from 2020)	Gas station	Tank	ICE	Automatic transmission + Drive axle
Trolley-Hybrid	Catenary	Battery (70 kWh)	Electric engine + power electronics	Drive axle
Overnight eBus	Conventional charging (conductive)	Battery (400 kWh)	Electric engine + power electronics	Drive axle
Opportunity eBus	Fast charging (conductive, inductive)	Battery (180 kWh)	Electric engine + power electronics	Drive axle
Brennstoffzellen-Hybrid	Compressed hydrogen station	Compressed hydrogen tank + Battery (30 kWh)	Fuel cell stack + Electric engine + power electronics	Drive axle

Source: Prof. Dr. Ralph Pütz

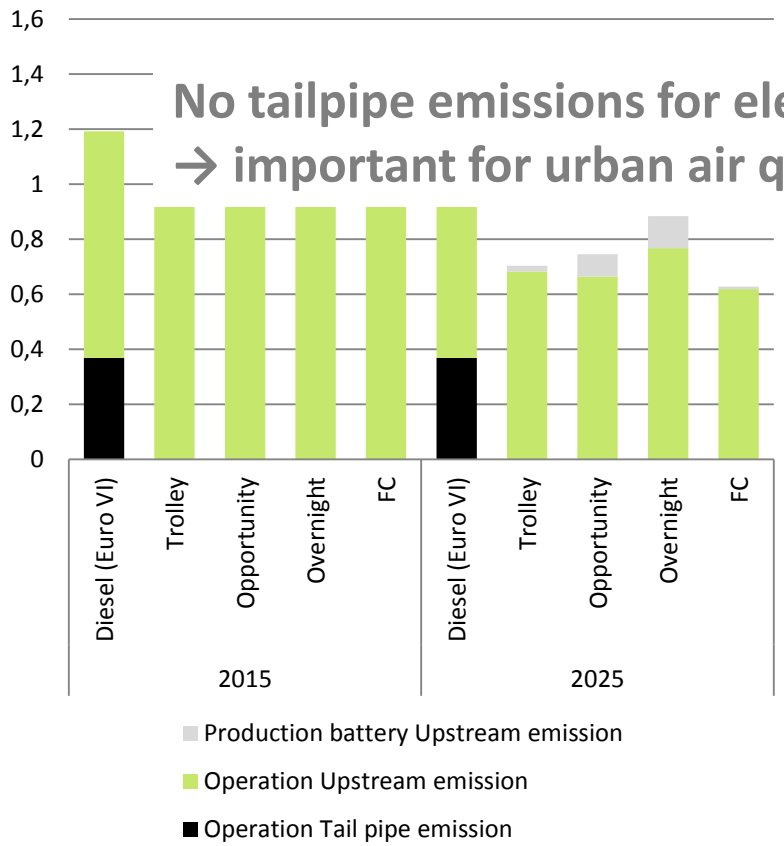
Comparison of different fuel concepts – GHG-Emissions (well-to-wheel + battery)



Source: Prof. Pütz (energy consumption), TREMOD/ Leitstudie 2011 (emissions operation), elCar (upstream emissions battery)

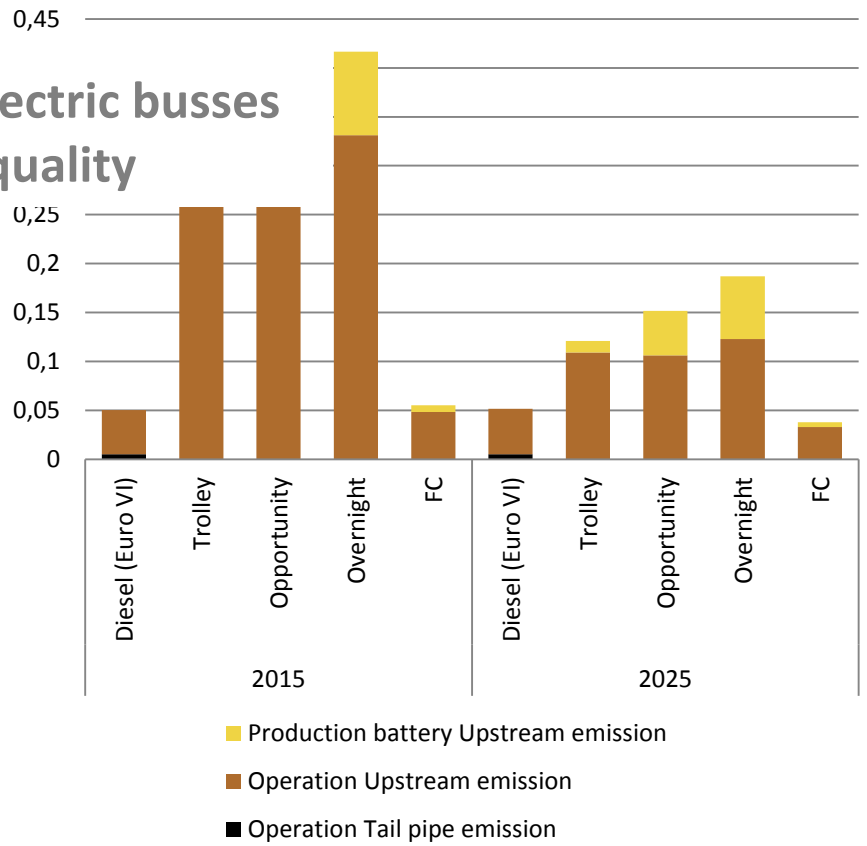
Comparison of different fuel concepts – air pollutants

NO_x-Emissions [g/Bus-km]



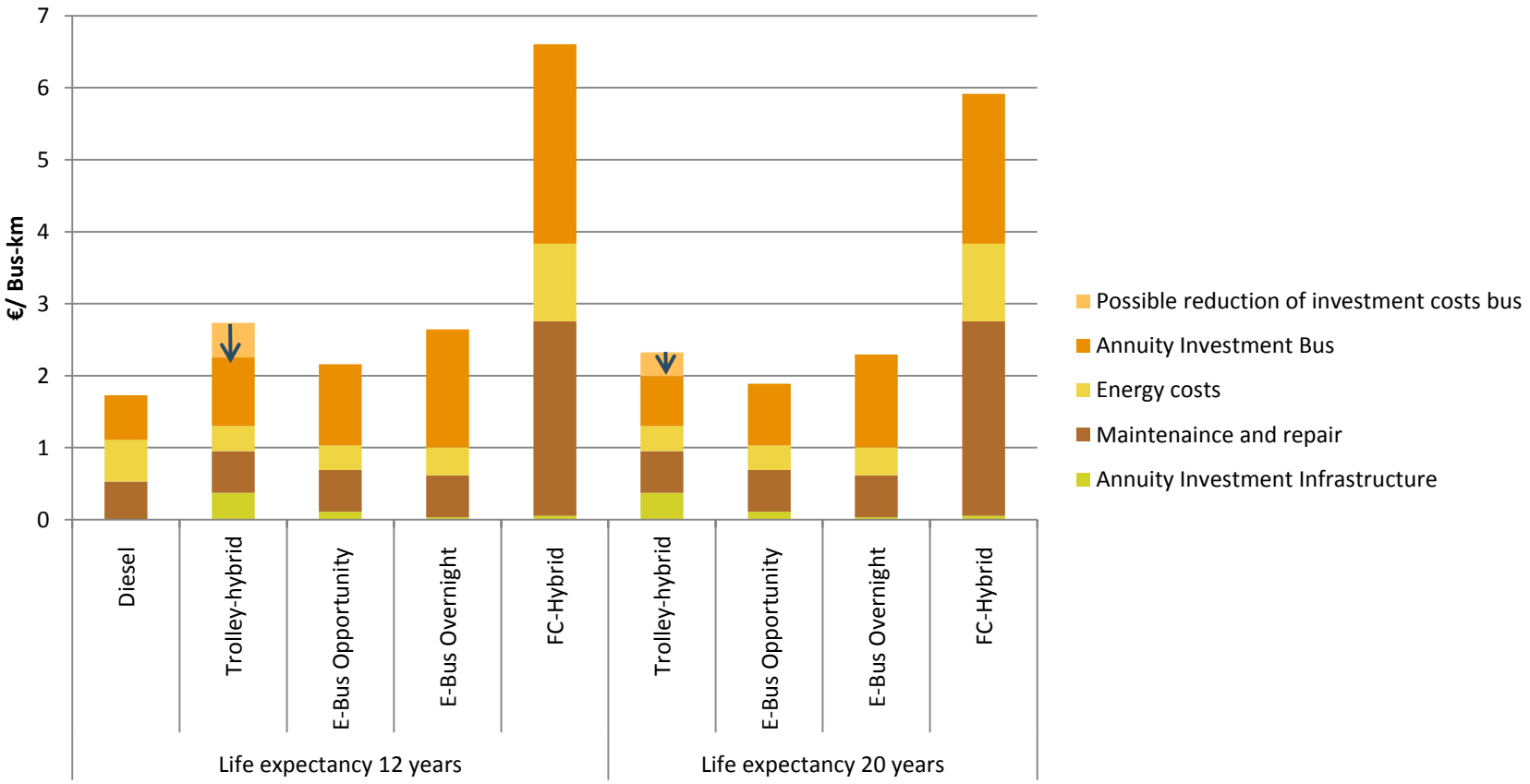
No tailpipe emissions for electric busses
→ important for urban air quality

PM-Emissions [g/Bus-km]



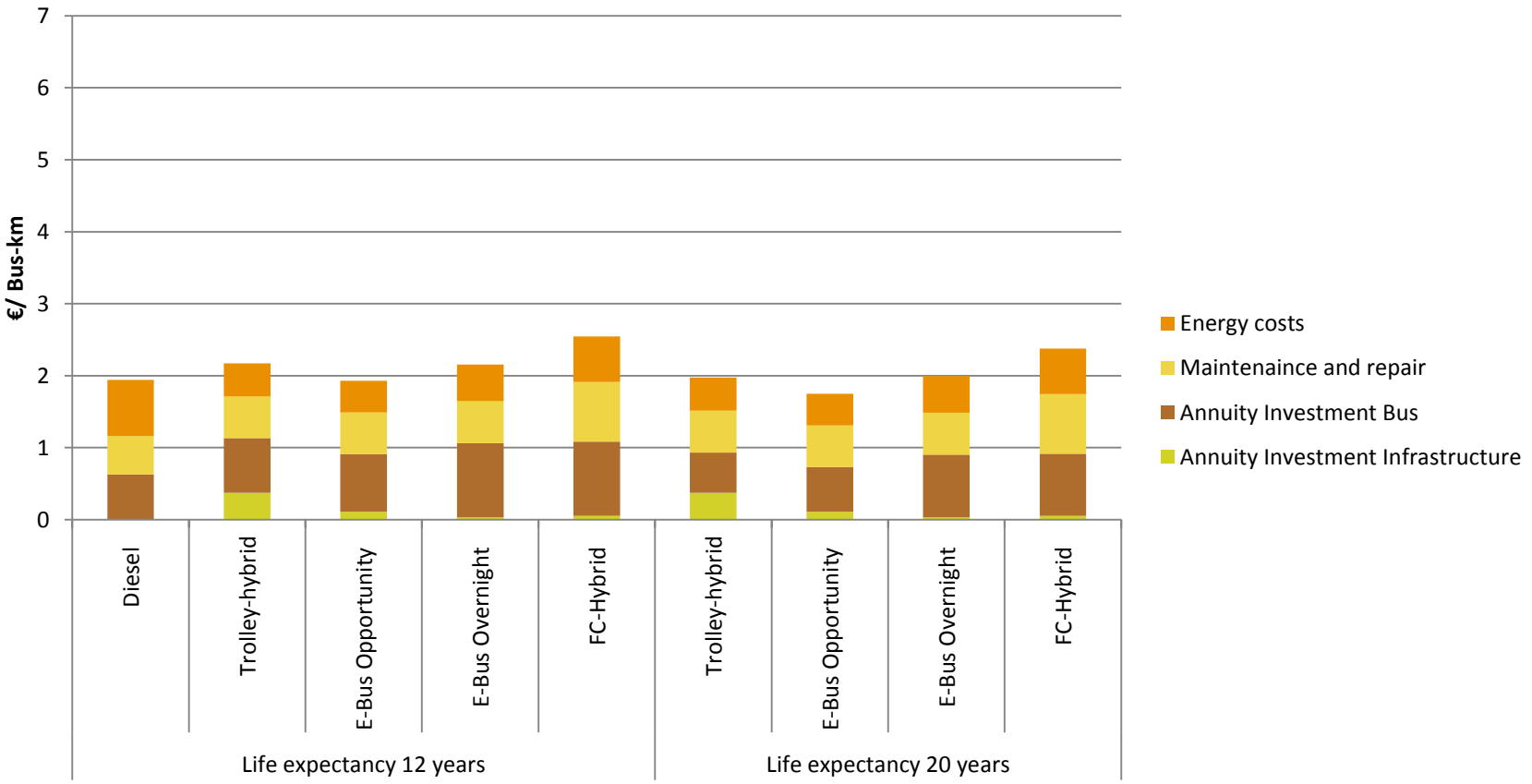
Source: Prof. Pütz (energy consumption), TREMOD/ Leitstudie 2011 (emissions operation), elCar (upstream emissions battery)

Total Costs of ownership per articulated bus (2015) – *preliminary results!*



 Source: Prof. Dr. Ralph Pütz

Total Costs of ownership per articulated bus (outlook 2025) – *preliminary results!*



Source: Prof. Dr. Ralph Pütz

First conclusions of the project

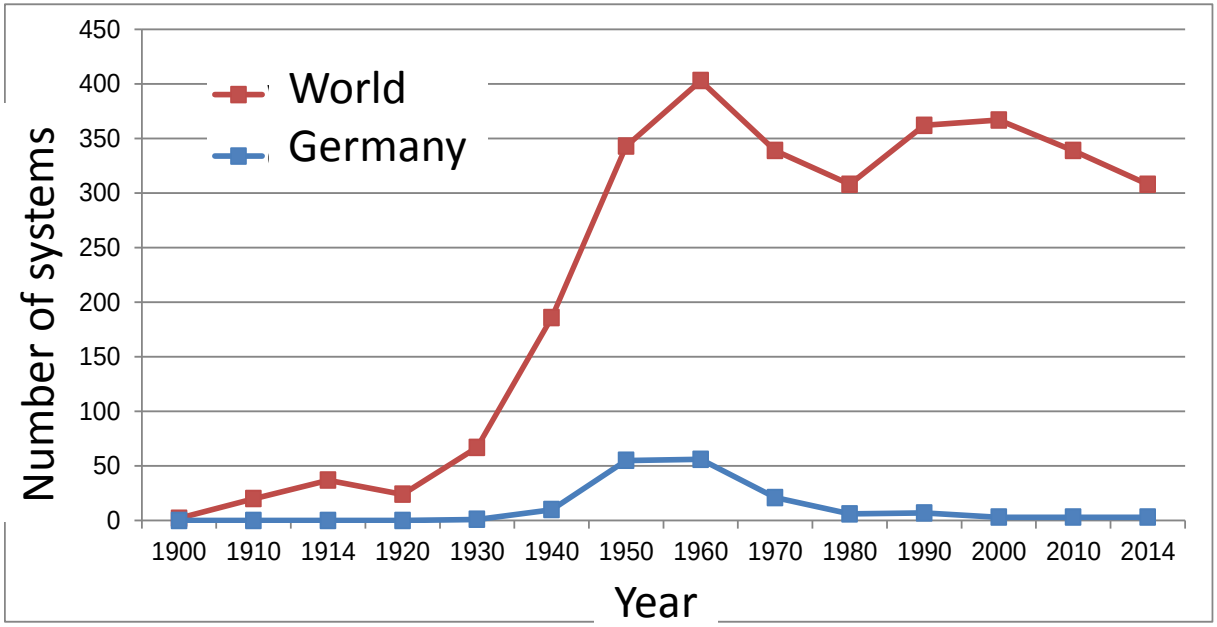
- Electric buses can reduce GHG-emissions through increased efficiency and the use of renewable energy
- All electric bus systems are subject to cost reductions in the next years…. the economic gap between conventional buses will significantly narrow in the next decade
- All electric bus technologies have specific opportunities and risks, depending on individual conditions (acceptance, operating strategy, etc.)…
  … therefore it is necessary to evaluate all alternative technologies regarding the implementation to specific cases (line/ net)

First conclusions of the project

- The Hybrid-Trolleybus is one feasible technology of electric buses
- The economical differences between the electric bus technologies depend
  - on the cost development and life expectancy of batteries and fuel cell stacks
  - the costs and utilisation of charging infrastructure

First conclusions of the project

- **The Hybrid-Trolleybus is one feasible technology of electric buses …**



… and maybe the Trolley bus has a comeback in Germany!

Source: based on [Spousta et al., 2013], [Müller, 1995], http://www.trolleymotion.eu/ (accessed 13.10.15)

INSTITUT FÜR ENERGIE- UND UMWELTFORSCHUNG HEIDELBERG

Thank you for your attention!

Hinrich Helms, Fabian Bergk and Nicolas Legner

Wilckensstraße 3 69120 Heidelberg Telefon +49 (0)6 221. 47 67 - 0 Telefax +49 (0)6 221. 47 67 - 19 www.ifeu.de