Comparative Analysis of Infrastructures: Hydrogen Fueling and Electric Charging of Vehicles in Germany

2018, JULY, 12TH | JOCHEN LINSSEN, MARTIN ROBINIUS, THOMAS GRUBE, MARKUS REUSS, PETER STENZEL, KONSTANTINOS SYRNANIDIS, DETLEF STOLTEN

6th Hellenic Forum for Science Technology and Innovation, Athens Greece

j.linssen@fz-juelich.de

Institute of Electrochemical Process Engineering (IEK-3)

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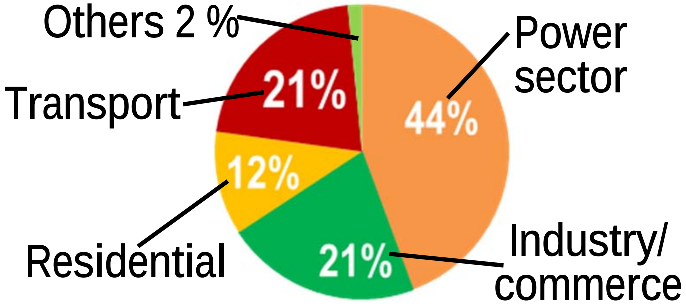
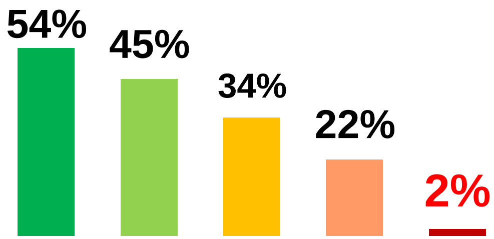
Motivation

CO_2 emissions for Germany in 2015 (total: 762 Mt)

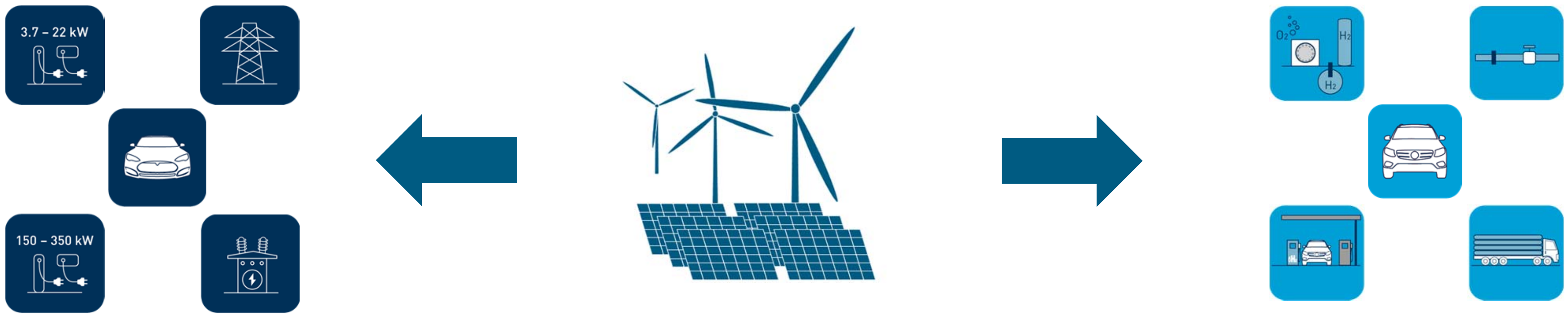


CO_2 emission reduction per sector 1990 to 2015



- Transport sector essential for reaching the ambitious climate protection goals
- Electric drivetrains key elements of low carbon, clean and energy-efficient transport based on renewable energy

Fuel Cell Electric Vehicles (FCEV) and Battery Electric Vehicles (BEV) require new energy supply infrastructures



Research Question

What are the investments, costs, efficiencies and emissions for an infrastructure capable of supplying hundred thousand or several million vehicles with hydrogen or electricity?

Approach

Meta-analysis of existing infrastructure scenario studies

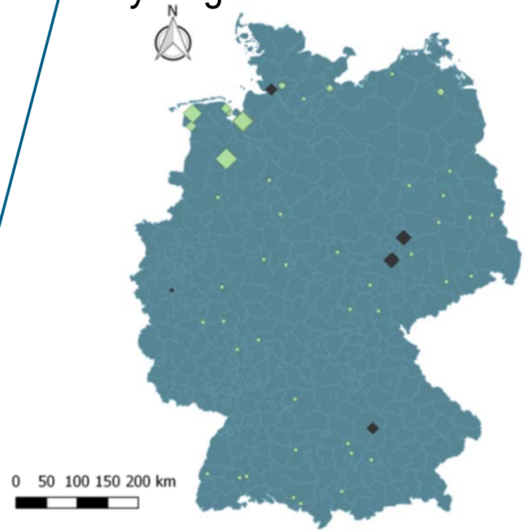
In depth scenario analysis of infrastructure designs, Case Study for Germany

Consistent scenario framework with different vehicle penetration

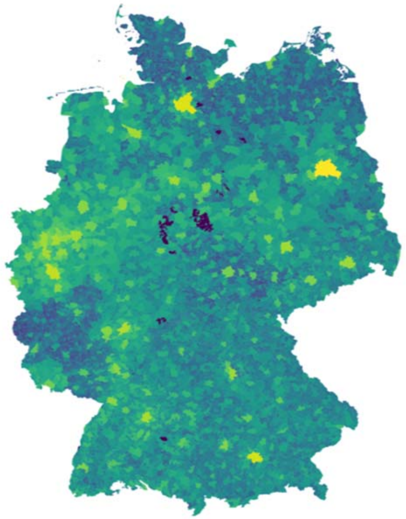
Spatially and temporally resolved models for generation, conversion, transport and distribution

Analysis of investment, costs, efficiencies and emissions

Hydrogen Production

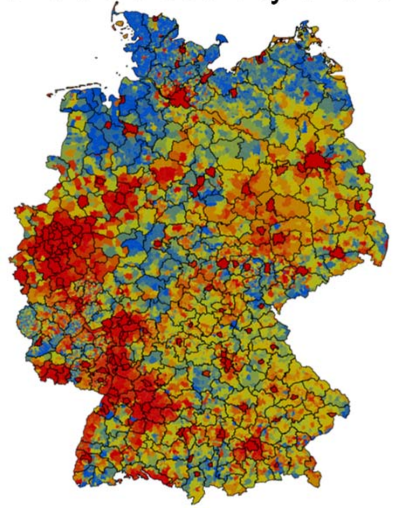


Electric Vehicle Penetration



Number of vehicles in million	0.1	1	3	5	10	20
Market penetration scenario	Ramp up					Mass market

Renewable electricity and demand



Electricity generation and grid

Status Quo of Infrastructure

Hydrogen Fueling

- Approx. 2,500 FCEV in operation worldwide
- **Worldwide:** 213 public Hydrogen Fueling Station (HRS) in operation by end of 2016: Japan (44%), USA (17%), Germany (13%)
- **Germany:** network with 30 HRS (06/2017); at present, 27 HRS under construction or planned in Germany,
  → target: 400 HRS before 2023
- Pipeline systems for hydrogen transport concentrated for chemical uses of hydrogen

Existing Hydrogen Pipelines (by 2017-05)	
The USA	2,608 km
Europe	1,598 km
of which in Germany	340 km
Rest of world	337 km
World total	4,542 km

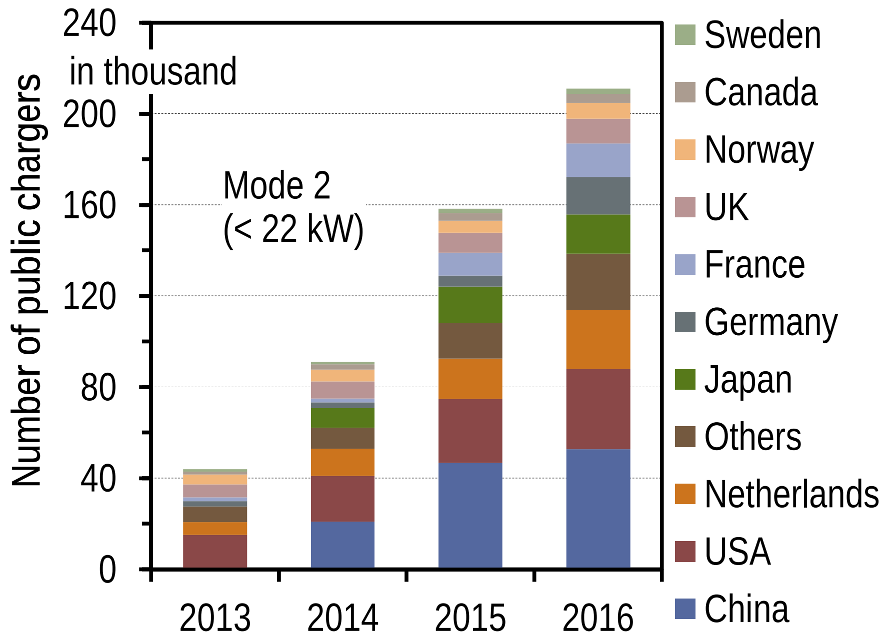
Sources: [9], [10], [14], [15]

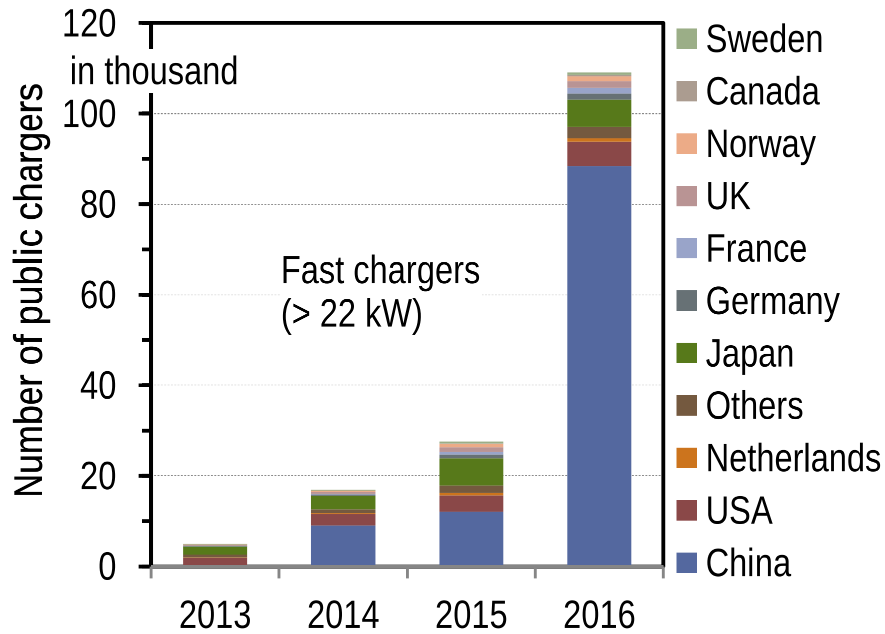
Roadmap for hydrogen refueling stations in Germany [12]

Status Quo of Infrastructure

Electric Charging

- In 2016, total BEV and PHEV stock was about 2 million worldwide, largely concentrated in China (32 %), followed by the United States (28 %) [16]
- Dynamic rollout of slow and fast charging worldwide
- Leading countries by end of 2016 China, the United States and the Netherlands
- For fast charging options (Modes 3 and 4) highest dynamic and absolute number in China





Sources: [16]

Meta Analysis

Selection criteria of scenario studies

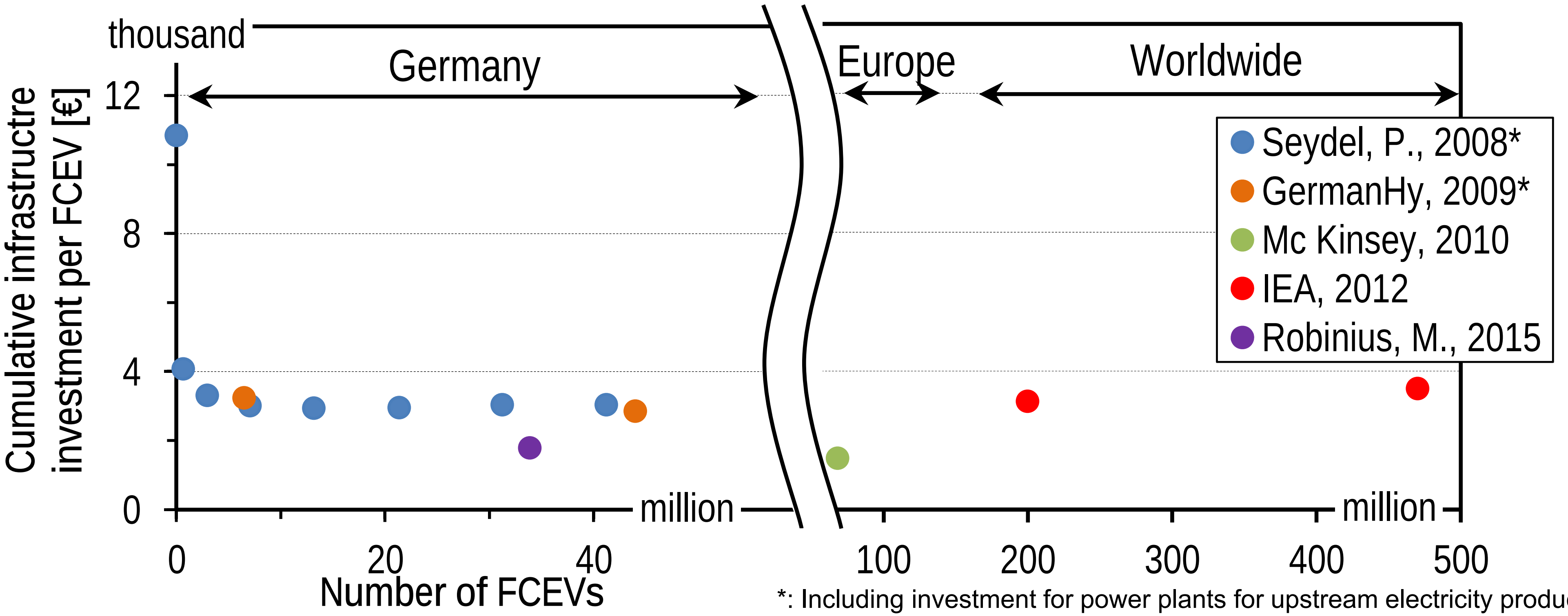
- Focus on Germany (broader context studies for EU, worldwide) and quantitative results; parameters: number of hydrogen fueling stations and charging points, cumulative investment for infrastructure set-up
- Total number of scanned literature sources: 79
- Selected studies for meta analysis: 25 (12 hydrogen and 13 electric charging)

Lessons learned of the meta analysis

- Mostly aggregated results and, in many cases without provision of techno-economic assumptions
- Lack of information in literature of important infrastructure parameters, e.g., hydrogen pipeline length, number of trucks for hydrogen transport → no meta-analysis possible
- Regarding electric charging studies: lack of studies concerning high xEV penetration scenarios, investment for infrastructure build-up, demand for fast-charging and impacts on the distribution grid

Meta Analysis

Hydrogen Fueling Infrastructure – Vehicle Specific Cumulative Investment



*: Including investment for power plants for upstream electricity production
McKinsey – EU&CH&NO, IEA - worldwide

- Cumulative investment differs significantly due to different assumptions e.g. consideration of power plant investment or number of fueling stations
- Specific cumulative investment per FCEV in the range of € 2,000 to 4,000 per FCEV
- Expected decreasing specific investment per FCEV with increasing FCEV stock (due to learning curve and economy of scale) is not observed

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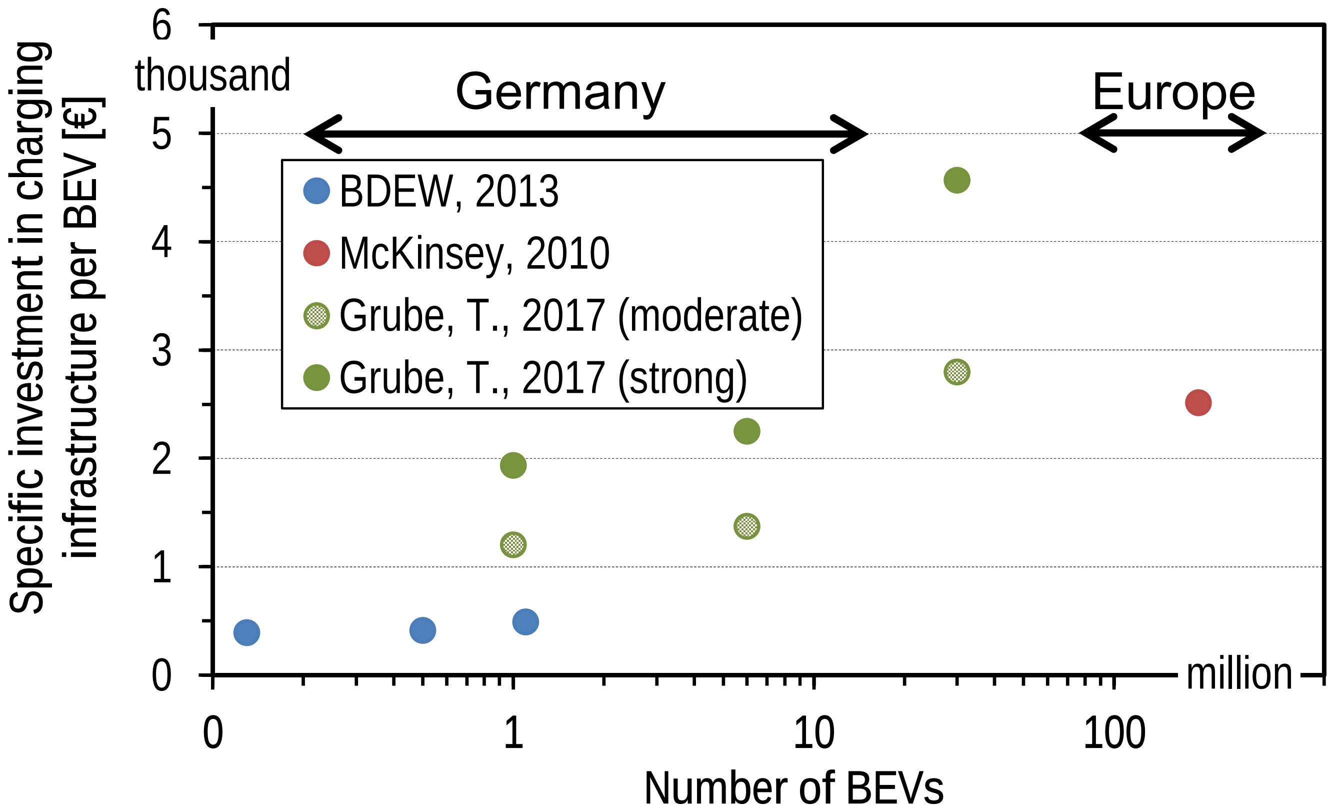
Meta Analysis

Electric Charging Infrastructure – Vehicle Specific Cumulative Investment



investment for public/semipublic normal & fast charging, private charging not included

- According to specific cumulative infrastructure investment per BEV is approx. € 500 per BEV stable for small BEV stocks
- Highest specific investment per BEV occur in the 30 million BEV scenario by Grube et al. => investment for additional grid reinforcements considered and high number of charging points (on-street and additional fast charging)

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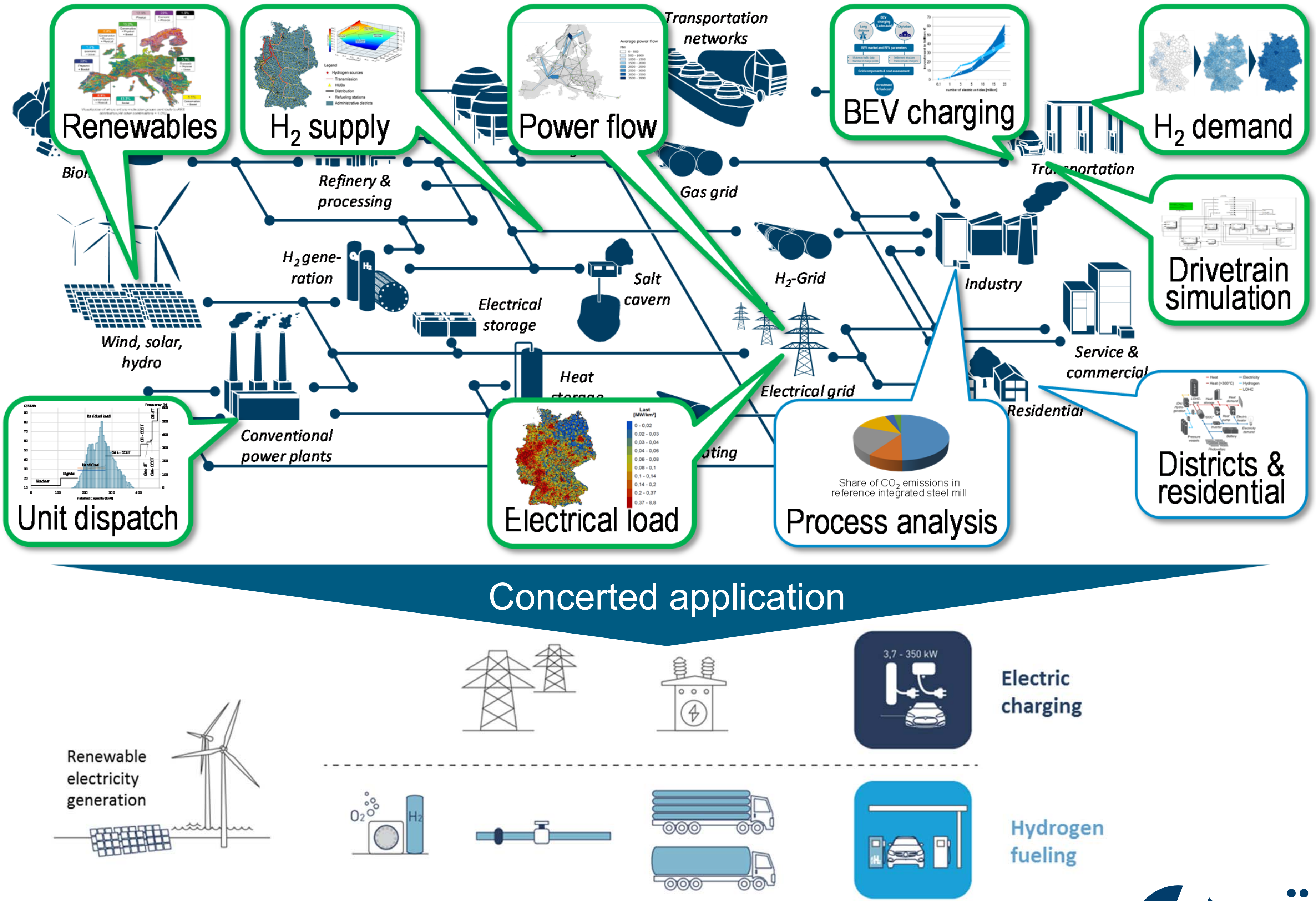
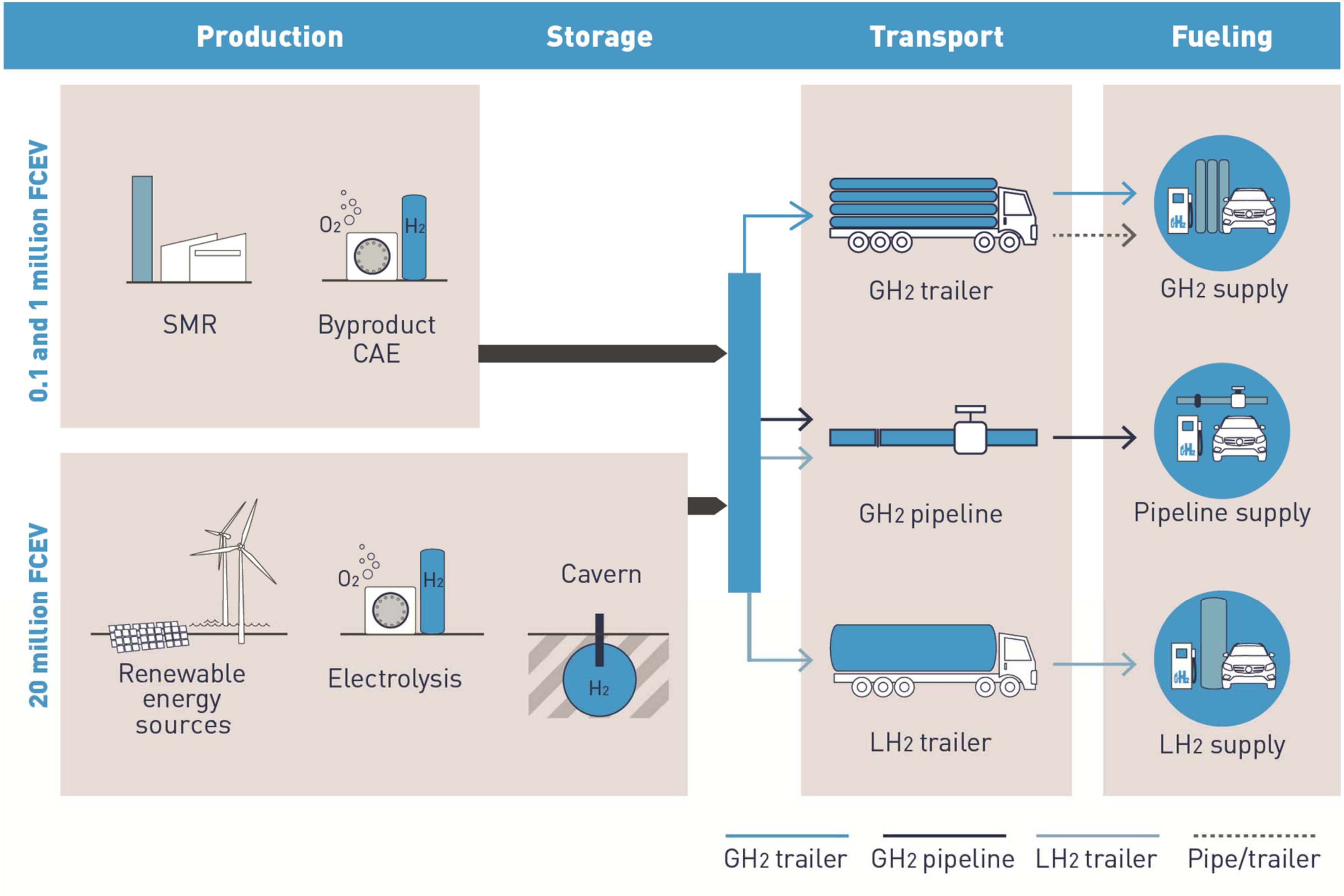
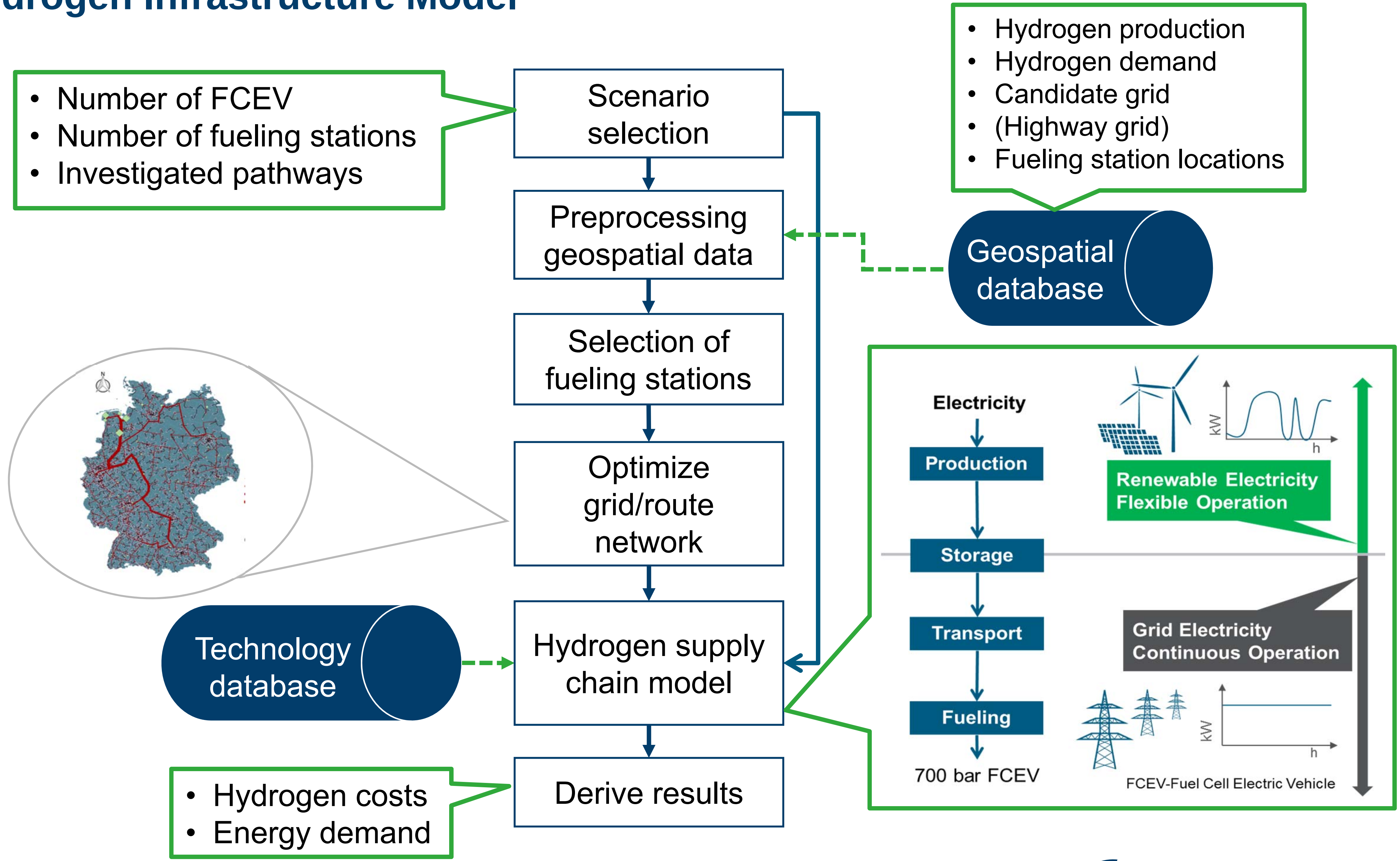
Applied Model Portfolio



Hydrogen Supply Pathways



Hydrogen Infrastructure Model



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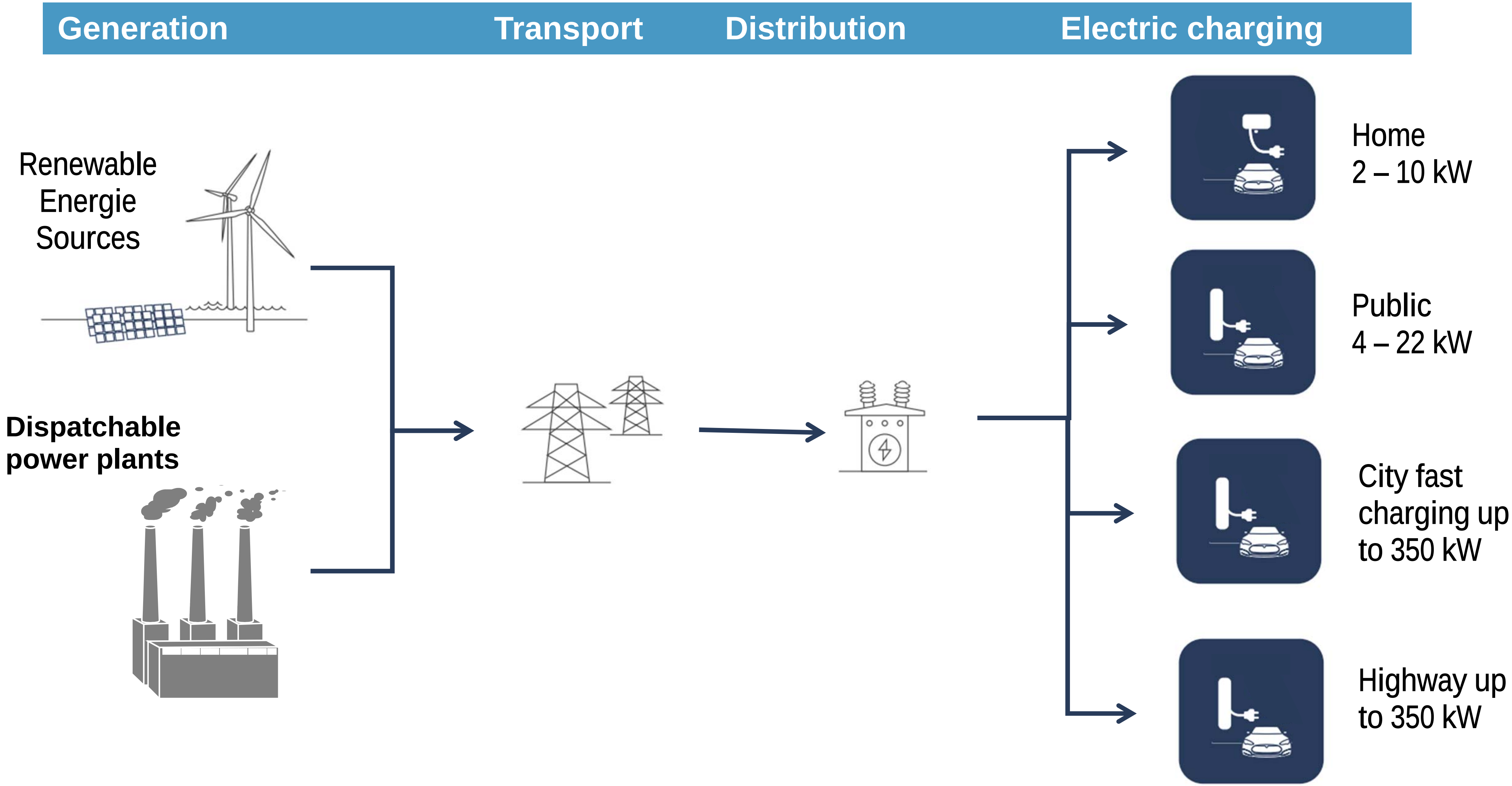
Electric Charging Pathways



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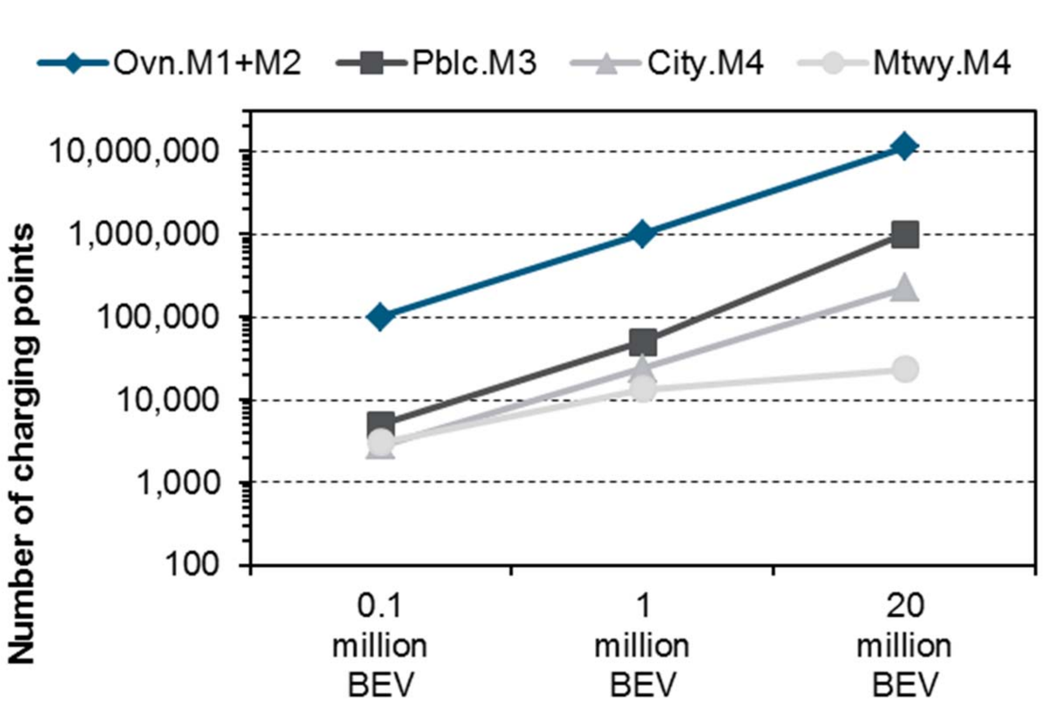
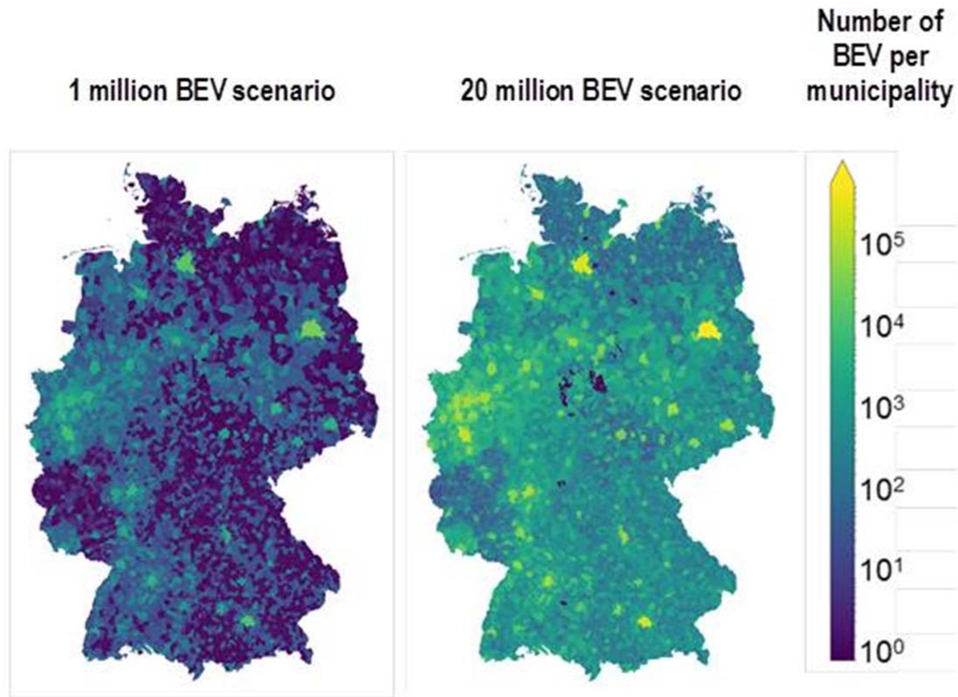
Number of BEV and Charging Points





OvN.M1+M2: Home and on-street chargers (Mode 1 and 2); Publc.M3: Public convenience chargers (Mode 3); City.M4: quick chargers in cities (Mode 4); Mtwy.M4: Quick chargers along motorways (Mode 4)

- Number of overnight chargers (Mode 1 & 2) increases with BEV number but with decreasing ratio:
  - 1 by 1 in the first two scenarios (all BEV have an overnight charging option)
  - 1 by 2 in the last scenario (only 58 % of all BEV have an overnight charging option)
- The ratio of BEV per Mode 4 charger increase due to decreasing charging frequency caused by higher driving range (battery capacity)

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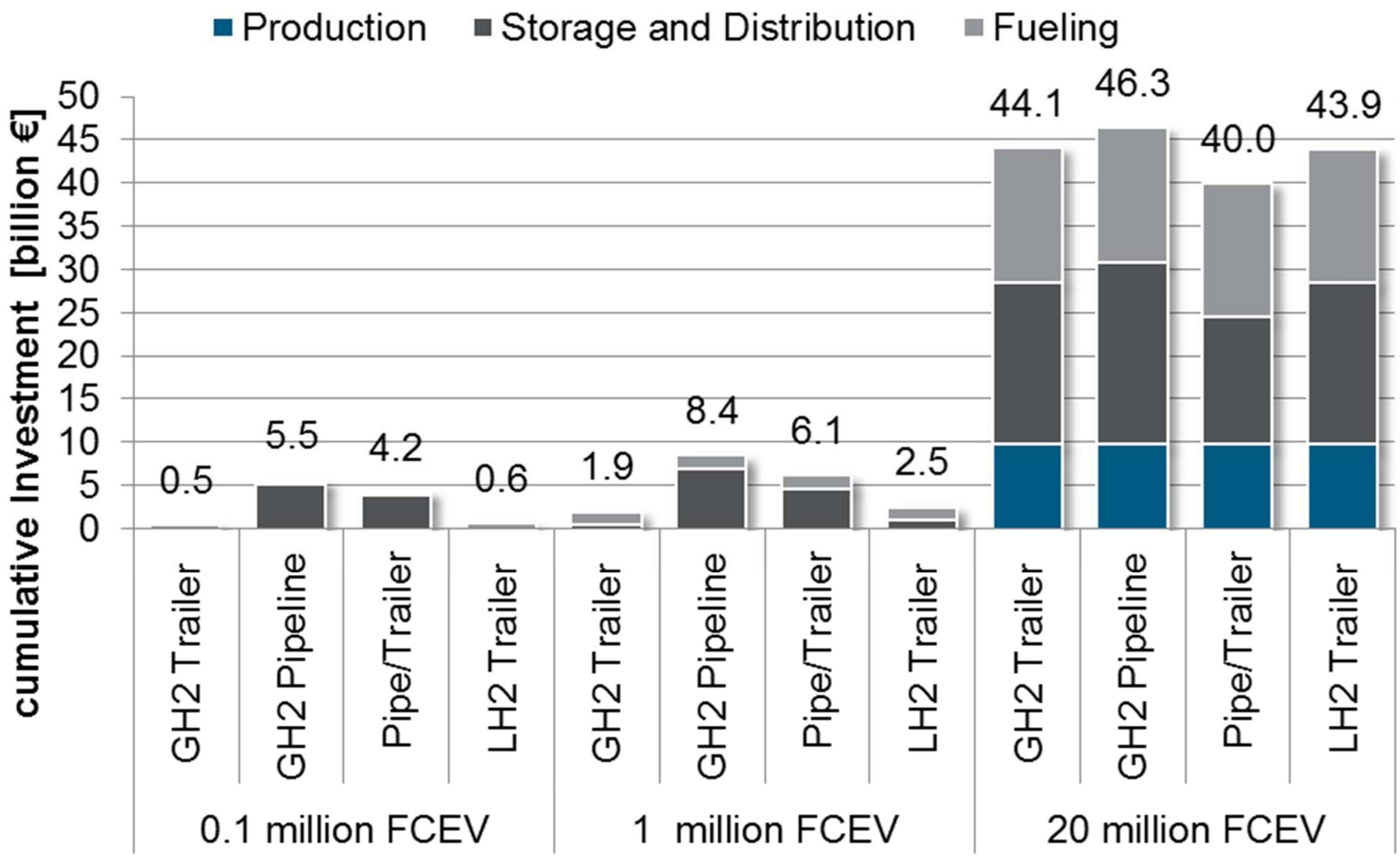
Infrastructure Designs

	Ramp up	Mass market		
	0.1 million	3 million	10 million	20 million
cable length		1,800 km	28,000 km	183,000 km
transformer		6,100	55,000	187,000
slow chargers (3.7 kW)	100,000 @ 3.7 kW	2.8 million	6.5 million	11 million @ 22 kW
fast chargers (150 kW)	6,000 @ 150 kW	81,000	175,000	245,000 @ 350 kW
storage capacity		2 TWh	5 TWh	10 TWh
electrolysis		3 GW	10 GW	19 GW
truck trailer	42	730	1,500	3,000
pipeline		12,000 km	12,000 km	12,000 km
fueling	400	1,500	3,800	7,000

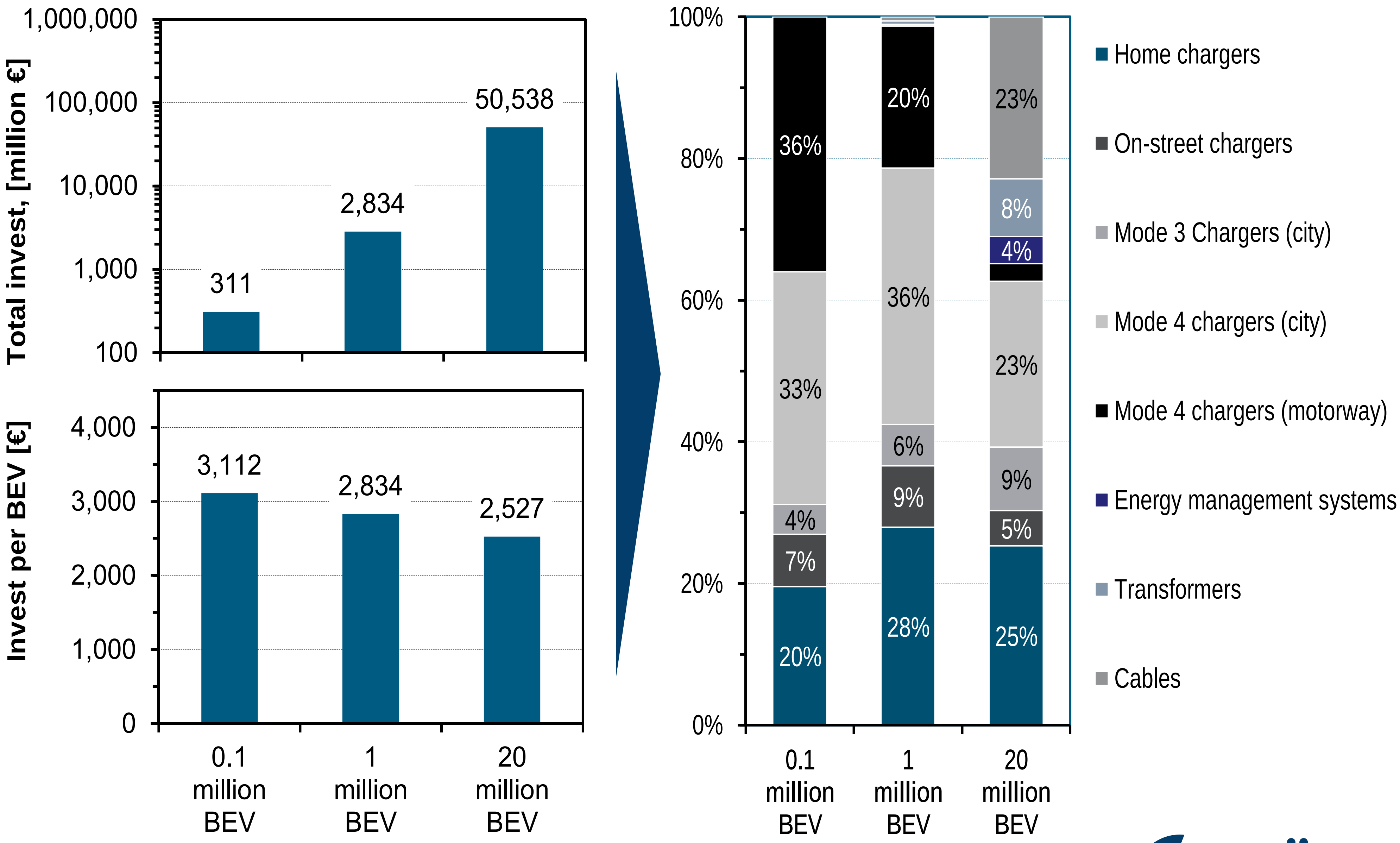
Total Cumulative Investment

Hydrogen Infrastructure



Total and Specific Investment

Charging Infrastructure



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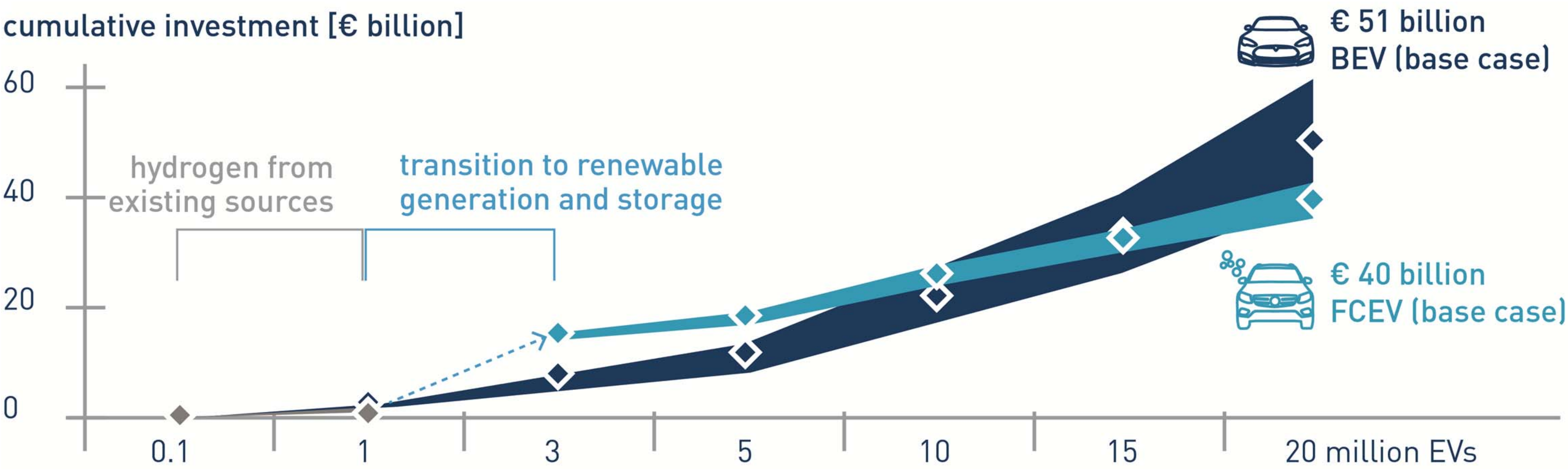
Cumulative Investment

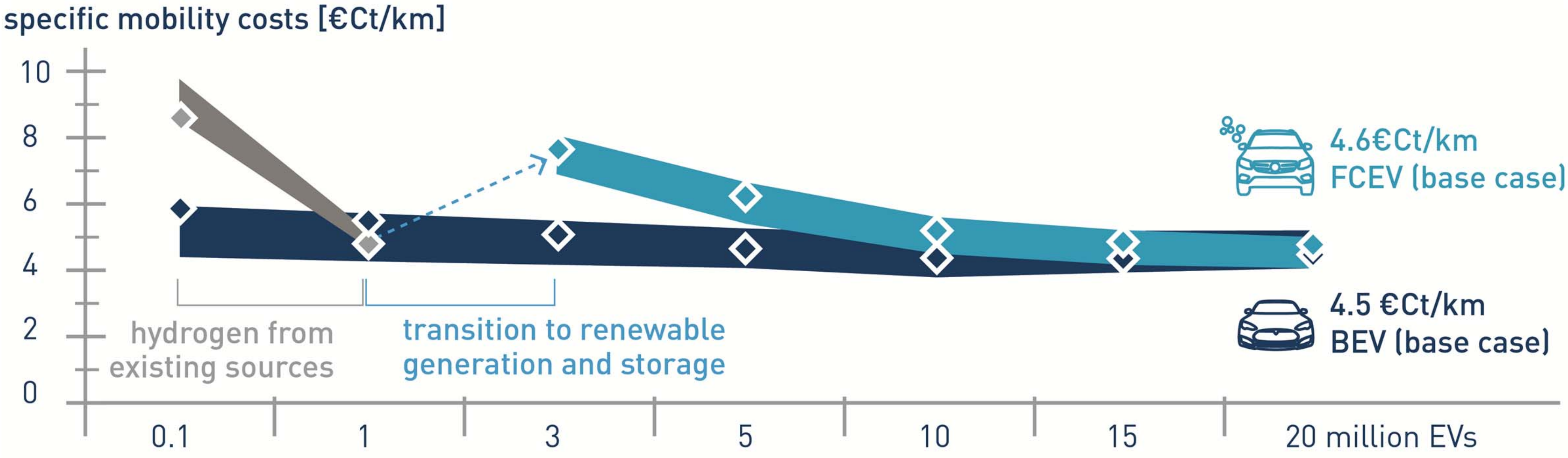
Infrastructure Roll-Out



- Hydrogen more expensive during the transition period to renewable electricity-based generation
- High market penetration: battery charging needs more investment than hydrogen fueling
- For both infrastructures investment low compared to other infrastructures

	Investment [€ billion]
Renewable electricity generation scenario	374
Electric grid enhancement plan 2030	34
Federal transport infrastructure plan 2030	265
Hydrogen fueling infrastructure	40
Electric charging infrastructure	51

Comparison of Mobility Costs



vehicle purchase and operation costs excluded

- For small vehicle fleets, i.e. 0.1 million cars, BEV fuel costs are significantly lower compared to FCEVs.
- Increase for hydrogen between 1 and 3 million cars results of switching to exclusive utilization of renewable energy for hydrogen production via electrolysis
- Mobility costs per kilometer are roughly same in the high market penetration scenario at 4.5 €ct/km for electric charging and 4.6 €ct/km → the lower efficiency of the hydrogen pathway is offset by lower surplus electricity costs.

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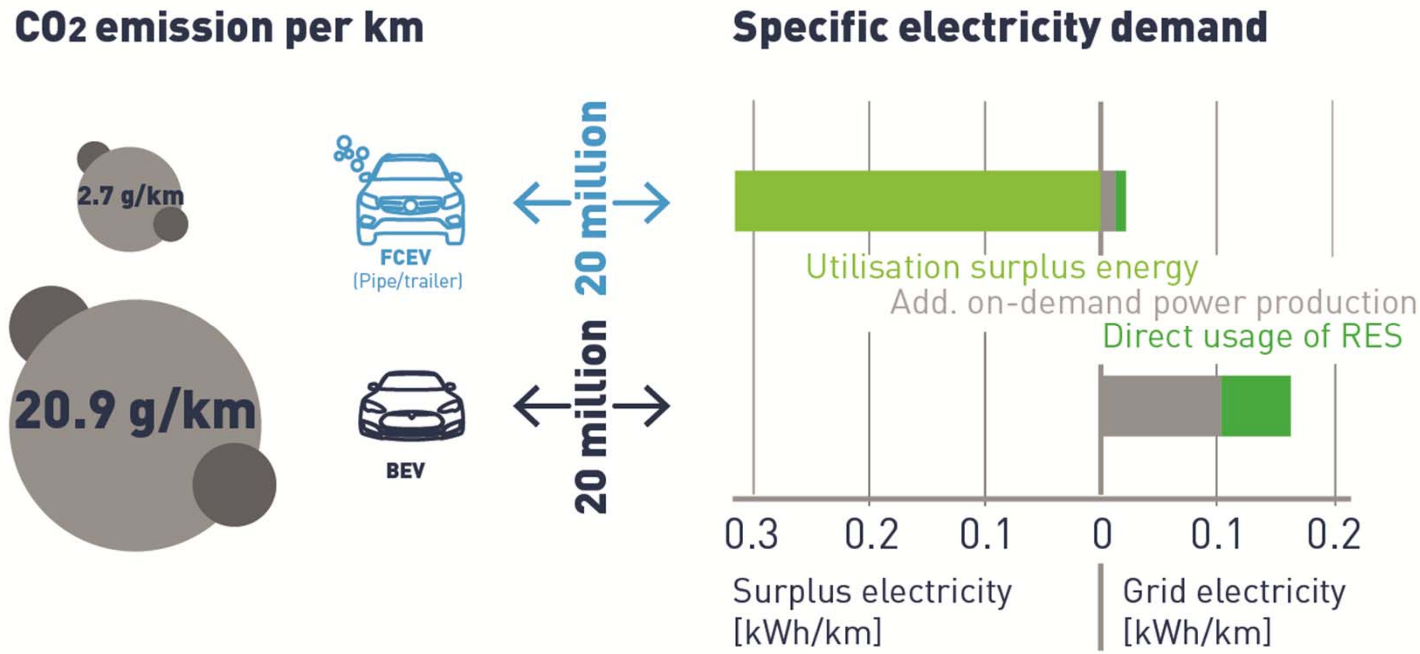
CO_2 Emissions & Electricity Demand



- Efficiency of charging infrastructure is higher, but limited in flexibility and use of surplus electricity
- Fueling infrastructure for hydrogen with inherent seasonal storage option
- Low specific CO2 emissions for both options in high penetration scenarios with advantage for hydrogen, well below the EU emission target after 2020: 95 g_{CO2}/km

Conclusions

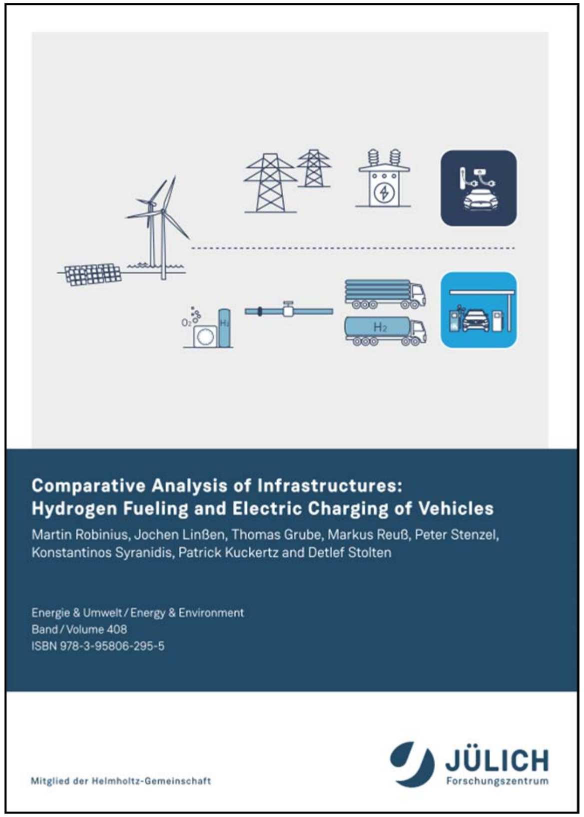
- Hydrogen and controlled charging key to integration of renewable electricity in transportation
- Complementary development of both infrastructures maximize energy efficiency, optimize the use of renewable energy and minimize CO_2 emissions
- Hydrogen infrastructure roll-out for transportation sector enables further large-scale applications in other sectors

Need for further research

- Integrated analysis of infrastructures and energy systems to identify win-win situations
- Modeling of BEV charging require in depth analysis: high uncertainties regarding number of chargers, siting and impact of fast charging on electric distribution grid
- Analyze the impact of new mobility and vehicle ownership concepts as well as autonomous driving on future transport supply concepts

Full Report Available

http://hdl.handle.net/2128/16709



Project team:

Martin Robinius, Jochen Linßen, Thomas Grube, Markus Reuß, Peter Stenzel, Konstantinos Syranidis, Patrick Kuckertz and Detlef Stolten

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