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1st IAEE Online Conference

POWER-TO-X MODELLING WITH IDENTIFICATION OF ECONOMIC KEY FACTORS USING A BUS FLEET SENSITIVITY ANALYSIS

SWK E² - Institute for Energy Technology and Energy Management

Prof. Dr.-Ing. Marc Gennat | Prof. Dr.-Ing. Jörg Meyer | Lukas Saars | Marius Madsen

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Agenda

- Introduction: Potentials of Hydrogen
- Hydrogen in Public Buses
- Case Study
- Modelling – Electricity Market and Hydrogen Storage
- Economic Efficiency Calculation – Results
- Conclusion

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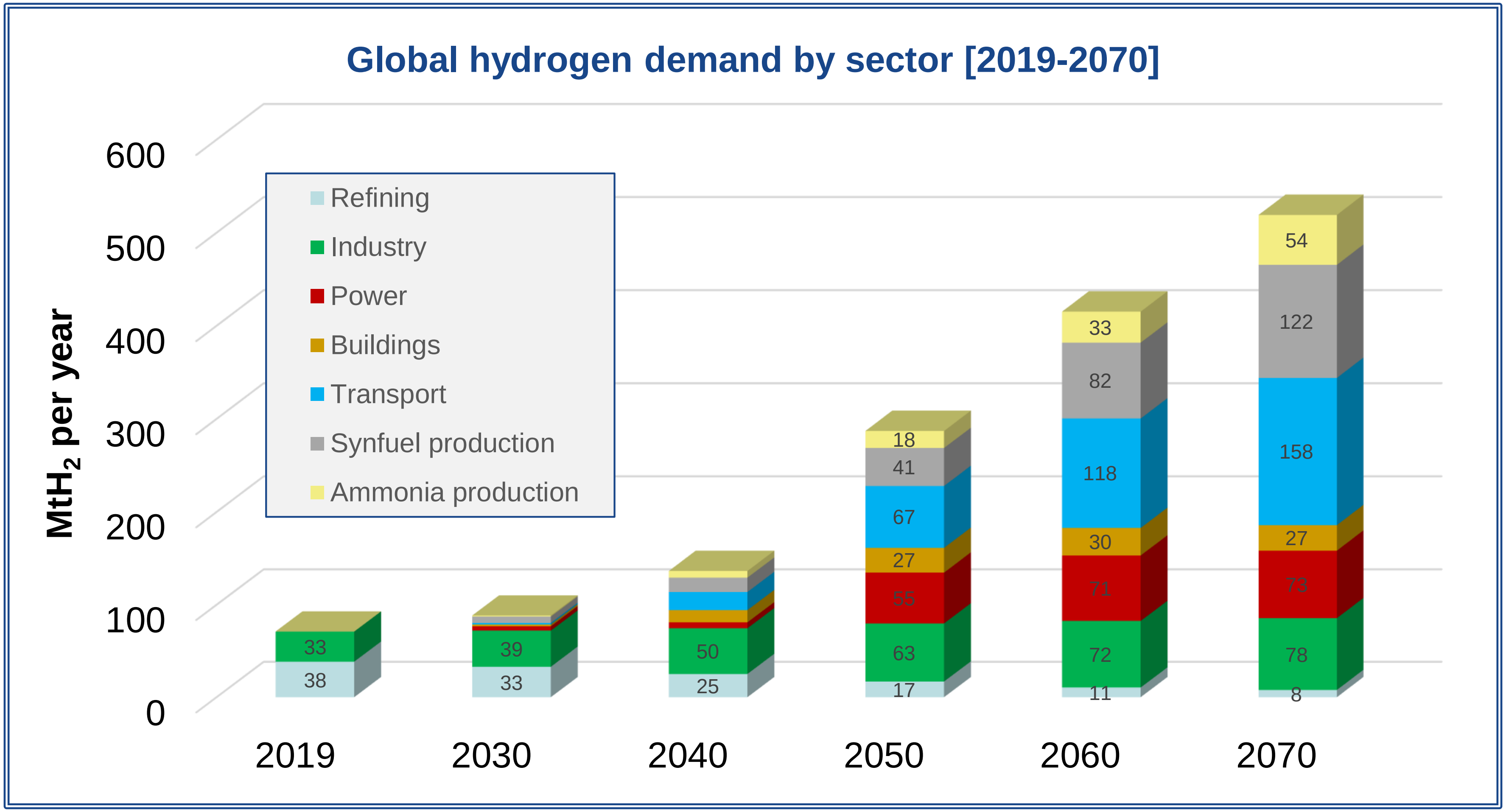
Introduction: Potentials of Hydrogen
Forecast: Global Hydrogen Demand by Sector



*[1] Reference: IEA – International Energy Agency (2020)

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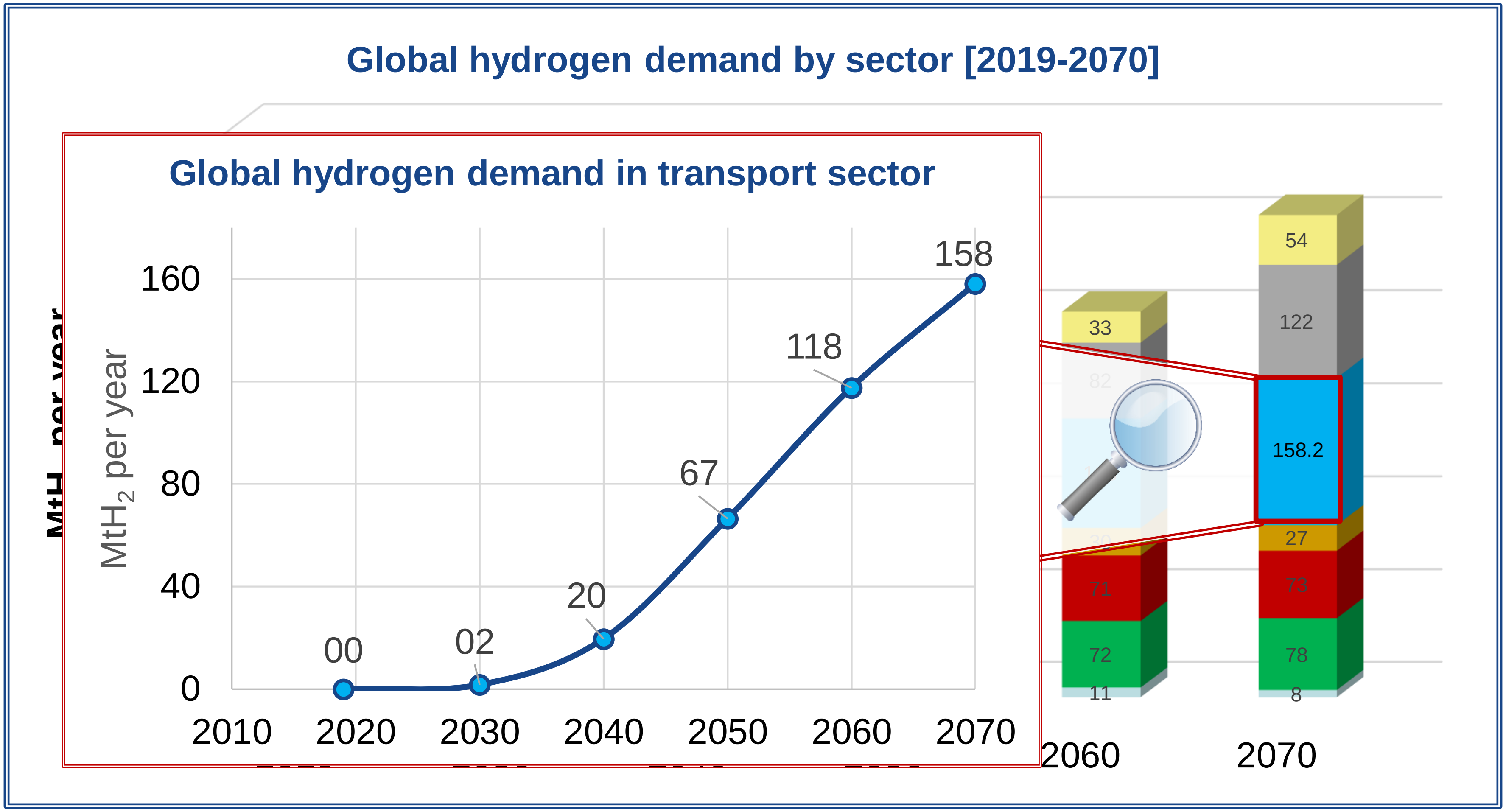

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Introduction: Potentials of Hydrogen
Hydrogen in Heavy-Duty Transport

- **Hydrogen** as **fuel** in the **transport sector** is seen as a **promising application case [2]**
- The **potential** is particularly great in those **applications** that are difficult to **electrify**
- These **applications** include **heavy-duty transport sector**, which is characterised by **little flexibility [3]**

Potential Advantages for the use of hydrogen in mobility

***[2] Reference:** S.A. Grigoriev, V.N. Fateev, D.G. Bessarabov, P. Millet (2020)
***[3] Reference:** J.p. Stempien, S.H. Chan (2017)

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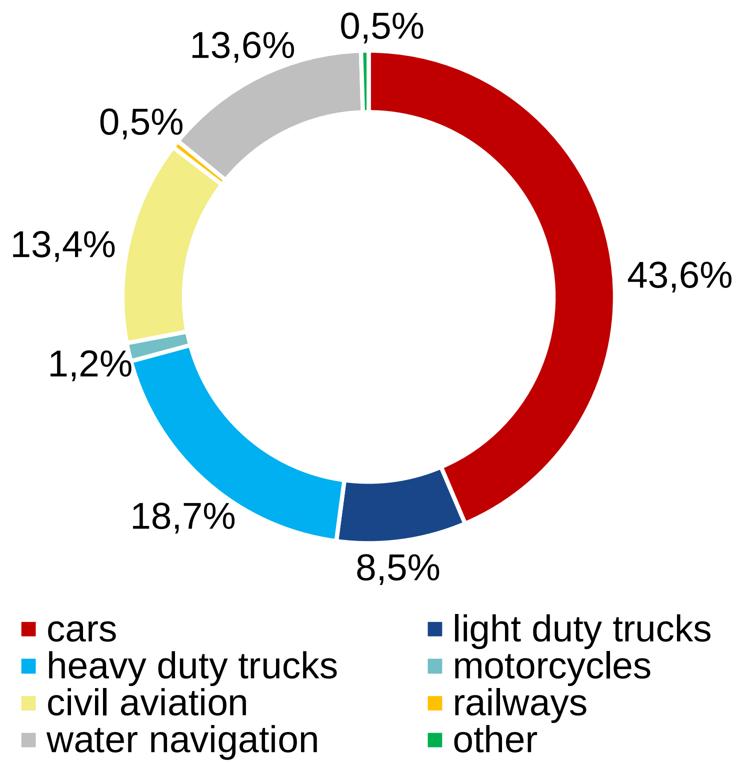
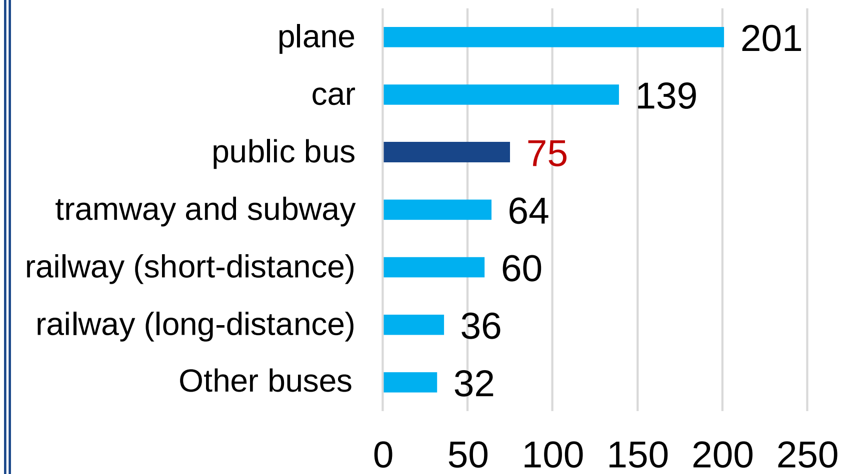
Hydrogen in Public Buses
Greenhouse Gas Emissions by Transport Mode

CO_2 Emissions by transport mode (2016)



*[4] **Reference:** IEA – International Energy Agency (2020)

CO_2 Emissions by transport mode [grams per person-kilometre]



Utilisation by transport mode	
plane	82%
car	1.5 passengers/vehicle
public bus	21%
tramway and subway	19%
railway (short-distance)	27%
railway (long-distance)	56%
couch	60%

*[5] **Reference:** Umweltbundesamt (2020)

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Case Study
Overal Objectives

Objectives

1. ✓ Development of a **tool** for the **economic evaluation** of a **bus fleet (FCBs)** with electrolyser, hydrogen filling station, hydrogen storage and compressor.

2. ✓ **Modelling** of the **hydrogen storage system** taking into account the favourable **electricity prices** on the stock exchange.

3. ✓ **Sensitivity analyses** with variation of the **key factors.**

4. ✓ Identify and quantify the **key factors** with a **significant influence** on the result of the **economic efficiency calculation**.

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Case Study
Bus Fleet – Central Assumptions

FCBs

Number of deployed FCBs	10
CAPEX – FCB	650,000 €
OPEX – FCB (kilometre specific)	0.38 €/km
Kilometre specific hydrogen demand	0.10 kg/km
Funding rate on innovative share	40%
Annual driving distance	65,000 km/a
Depreciation period	11 a

Diesel-powered bus (are taken into account as avoided costs)

CAPEX Diesel-powered bus	240,000 €
OPEX – Diesel-powered bus (kilometre specific)	0.295 €/km
Kilometre specific diesel demand	0.35 L/km
Annual driving distance	65,000 km/a
Depreciation period	11 a
Costs Diesel	0.90 €/L

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Modelling - Electricity Market and Hydrogen Storage
Target Function

Formulation of objective function:

$$\min_{x} \; c^T x$$

Decision vector *x* with length ***X***

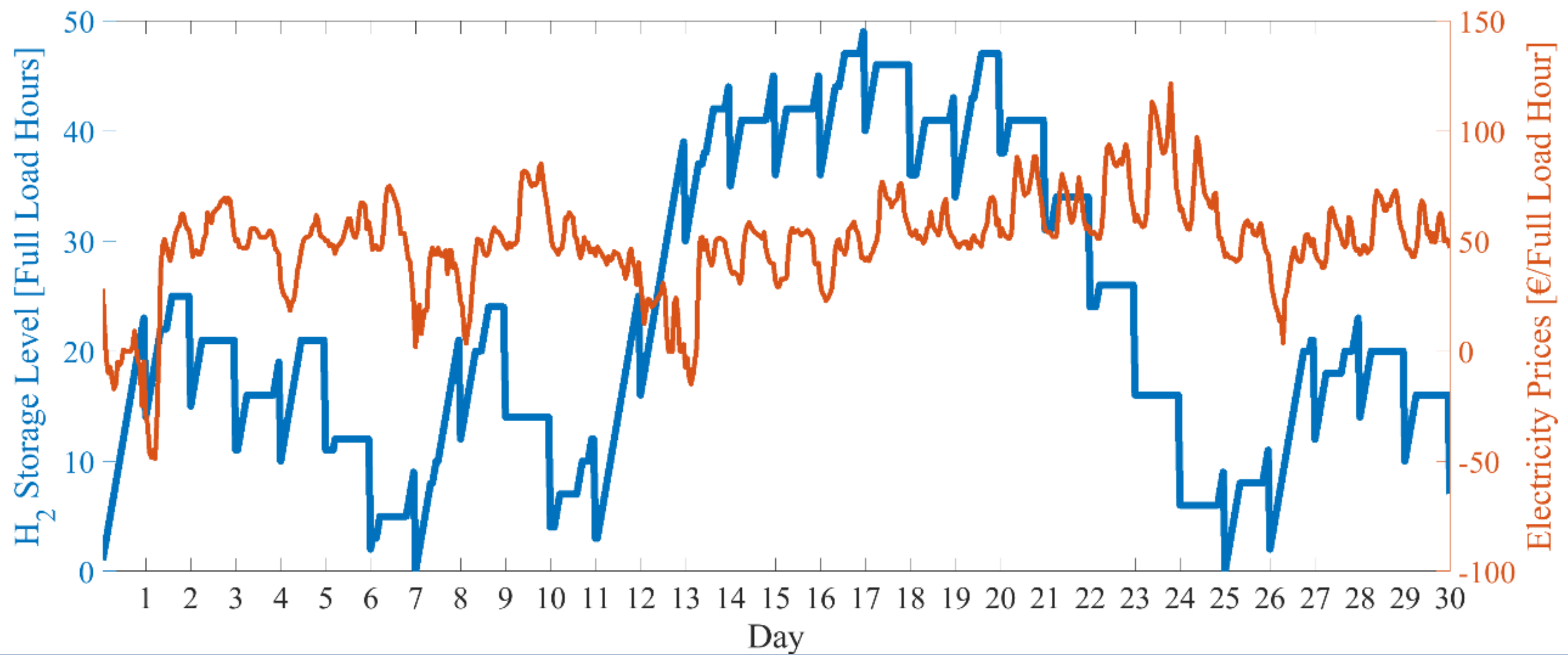
$$x^T = \Big(\overbrace{x_{h=1}\; x_{h=2} \cdots x_{h=24}}^{day=1} \;\; \overbrace{x_{h=25}\; x_{h=26} \cdots x_{h=48}}^{day=2} \;\; \overbrace{x_{h=49}\; x_{h=50} \cdots x_{h=72}}^{day=3} \Big) \;\ldots$$

Vector *c* (C=*X*) contains the hourly exchange electricity prices

$$c^T = \Big(\overbrace{c_{h=1}\; c_{h=2} \cdots c_{h=24}}^{day=1} \;\; \overbrace{c_{h=25}\; c_{h=26} \cdots c_{h=48}}^{day=2} \;\; \overbrace{c_{h=49}\; c_{h=50} \cdots c_{h=72}}^{day=3} \Big) \;\ldots$$

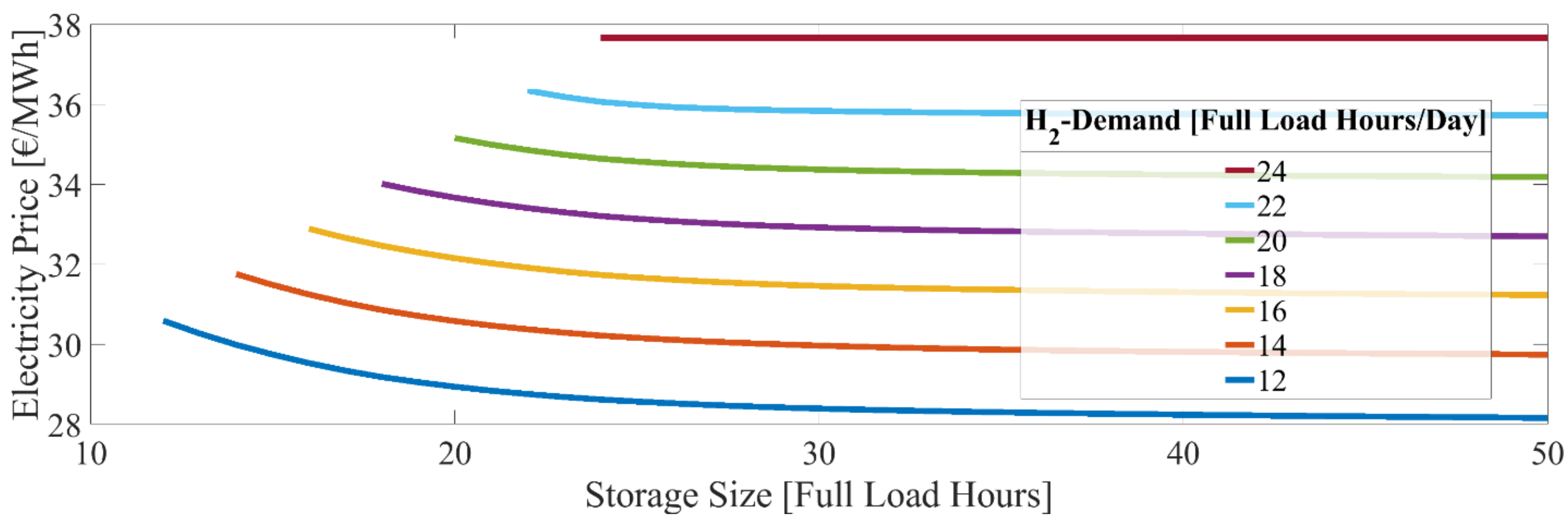
Modelling - Electricity Market and Hydrogen Storage
Filling the Hydrogen Storage

In the following, the H_2 level is shown for an exemplary storage with a capacity of 50 full load hours over 30 days!



Modelling - Electricity Market and Hydrogen Storage
Design of a Hydrogen Storage

- Use of the unit "electrolyser full load hours" as storage quantity
  → Transferability to all constellations (demand, storage, electrolyser)
- Model calculated for different requirements and storage sizes



- The economic optimisation potential due to the larger design of the hydrogen storage tank is very low!
- Therefore the storage is designed to be small in the tool (assumption: 780 kg)!

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Modelling - Electricity Market and Hydrogen Storage
Design of a Hydrogen Storage

- Use of the unit "electrolyser full load hours" as storage quantity
  → Transferability to all constellations (demand, storage, electrolyser)

Abstract:

- Bigger storage or electrolyser → higher optimisation potential
- However: potential exhausted above a certain size

→ Results are considered in the business case

nk is very low!

- Therefore the storage is designed to be small in the tool (assumption: 780 kg)!

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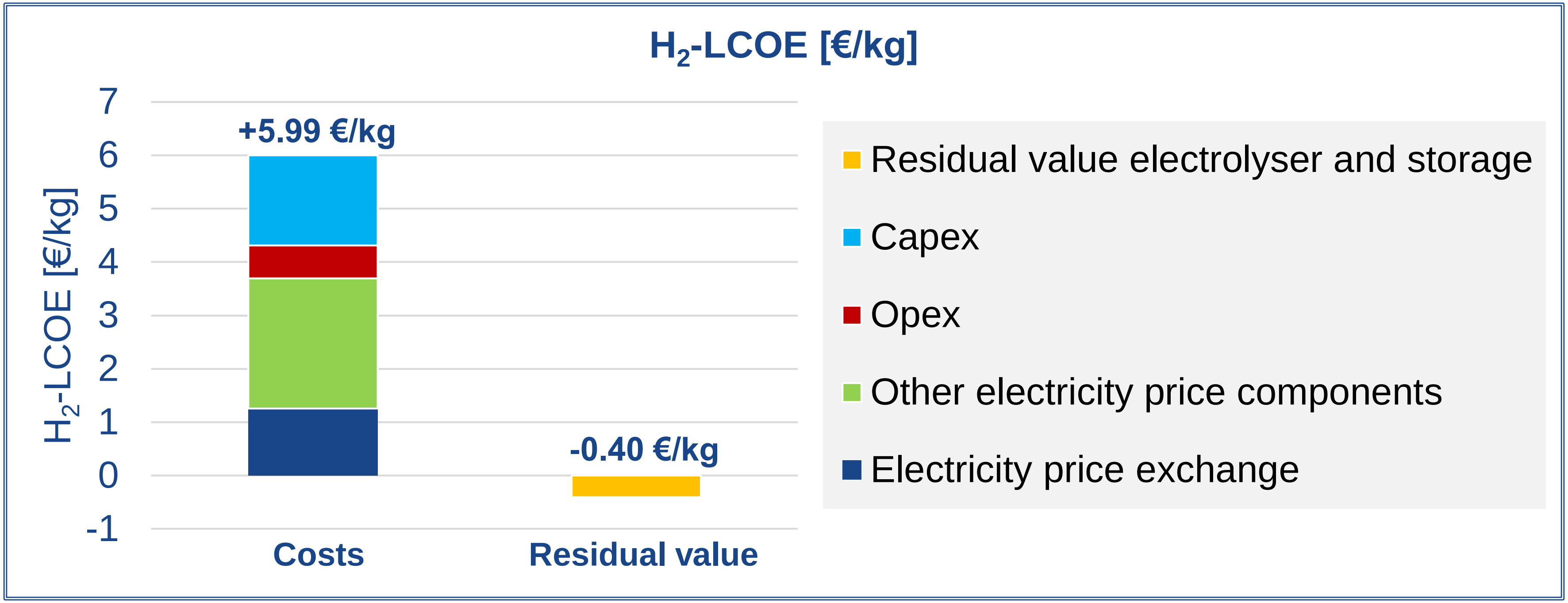
Economic Efficiency Calculation - Results
Levelized Cost of Energy - Hydrogen



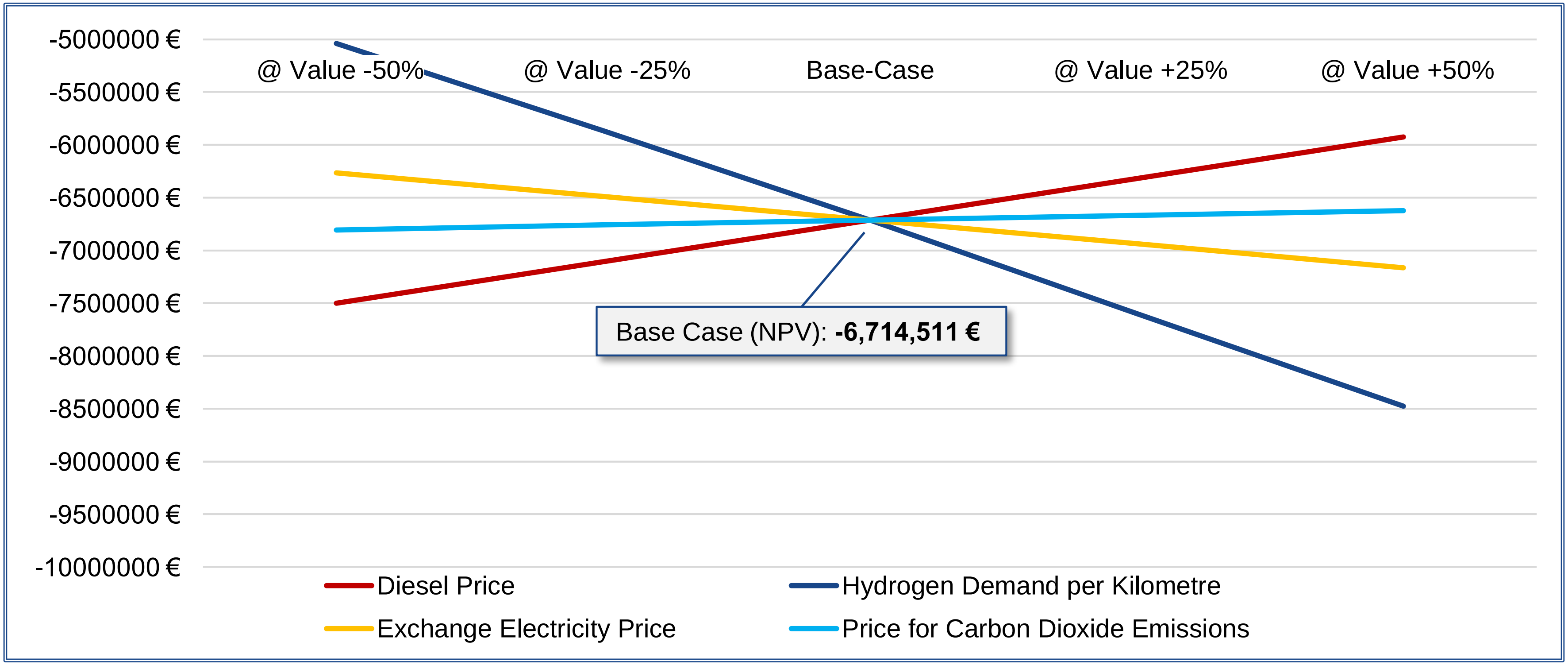
Results (including residual values):

- H_2-LCOE **5.60 €/kg**
- CO_2-Savings **603 t/a**
- Net Present Value **-6.71 Mio. €**

Period under review: 20 years

Economic Efficiency Calculation - Results
Sensitivity Analysis

Key Factors	@ Value -50%	@ Value -25%	Base Case	@ Value +25%	@ Value +50%
Diesel Price	0.45 €/l	0.68 €/l	0.90 €/l	1.13 €/l	1.35 €/l
Hydrogen Demand per Kilometre	0.05 kg/km	0.08 kg/km	0.10 kg/km	0.13 kg/km	0.15 kg/km
Exchange Electricity Price	20.96 €/MWh	31.43 €/MWh	41.91 €/MWh	52.39 €/MWh	62.87 €/MWh
Price for Carbon Dioxide Emissions	20 €/t	30 €/t	40 €/t	50 €/t	60 €/t



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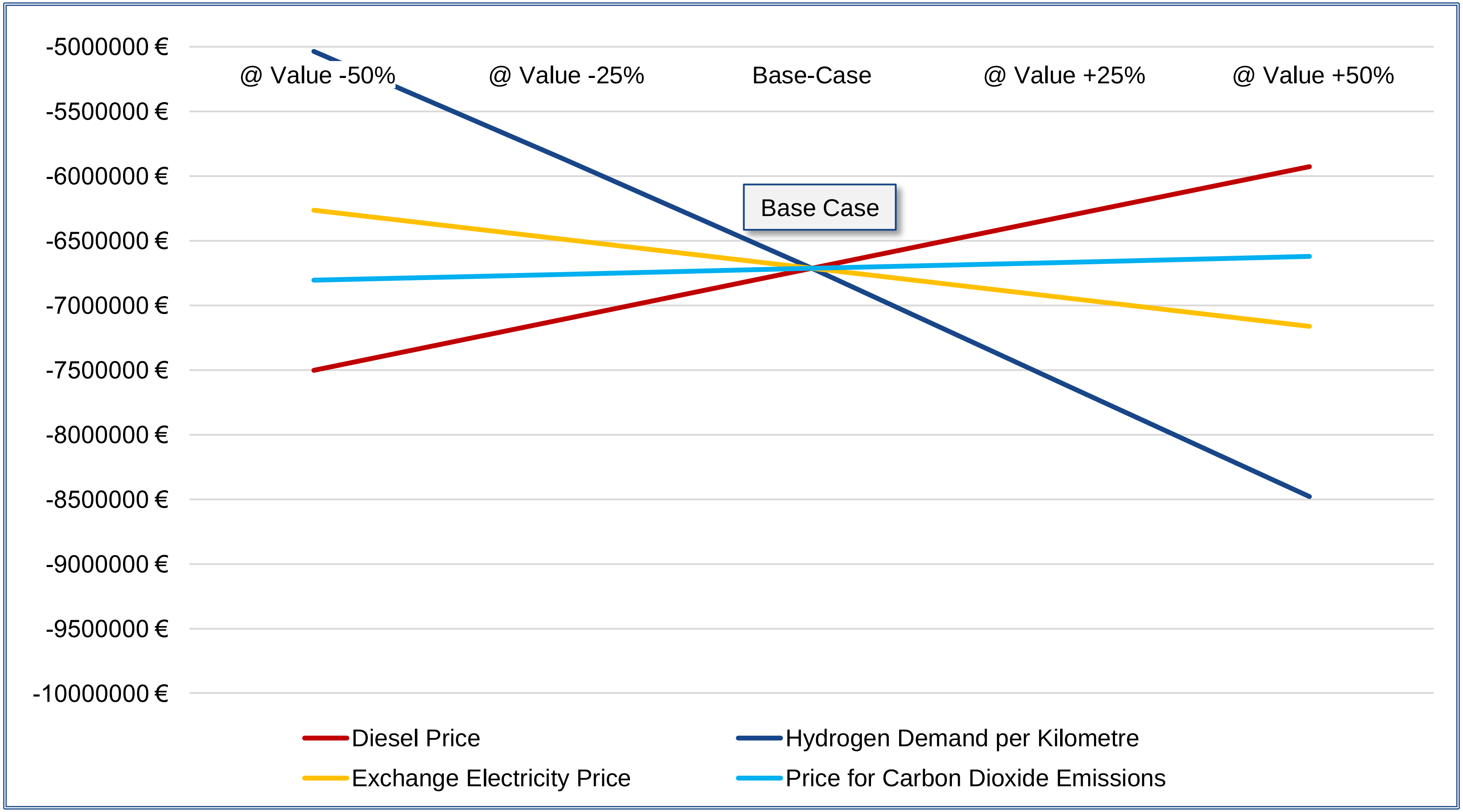
Economic Efficiency Calculation – Net Present Value
Sensitivity Analysis



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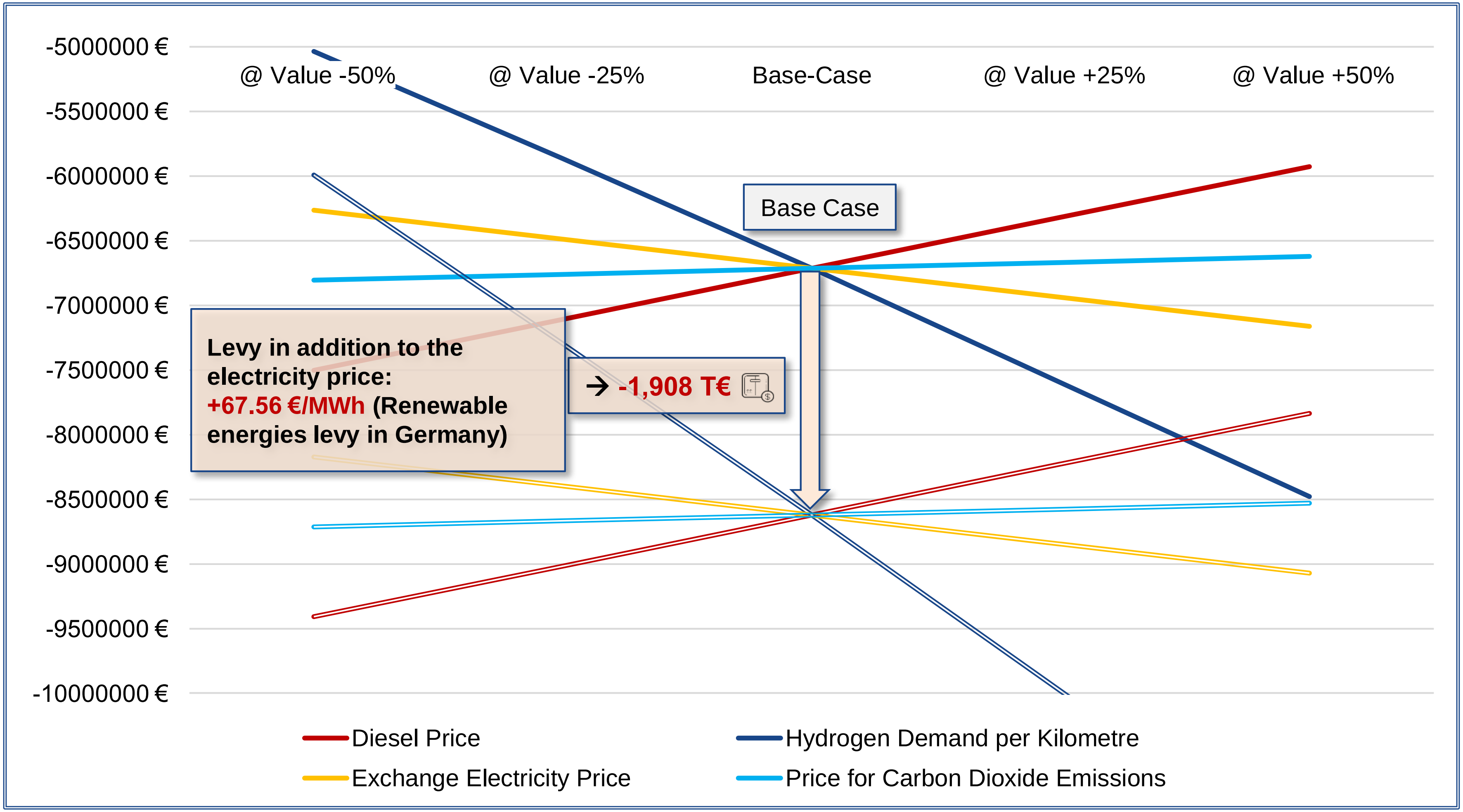

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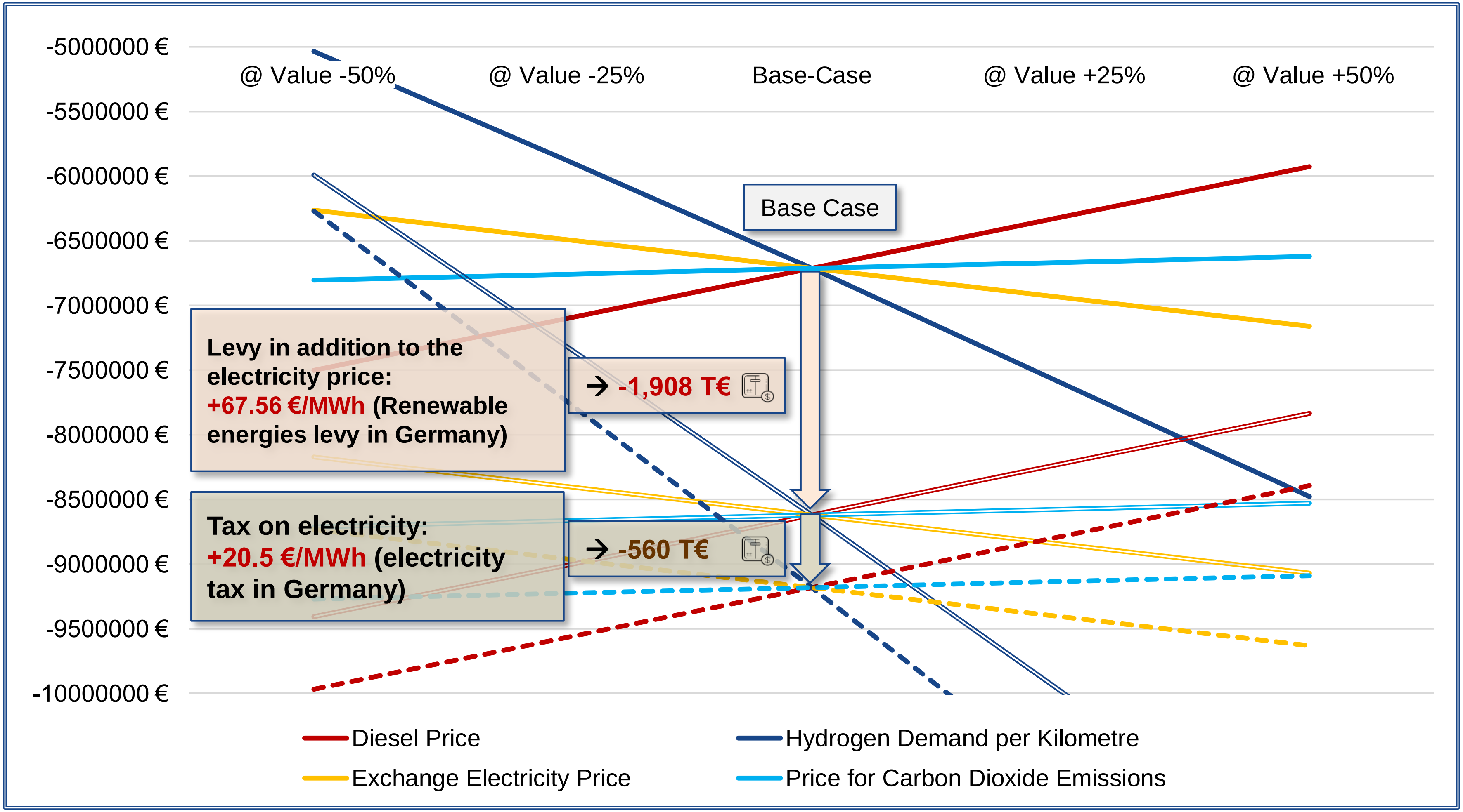

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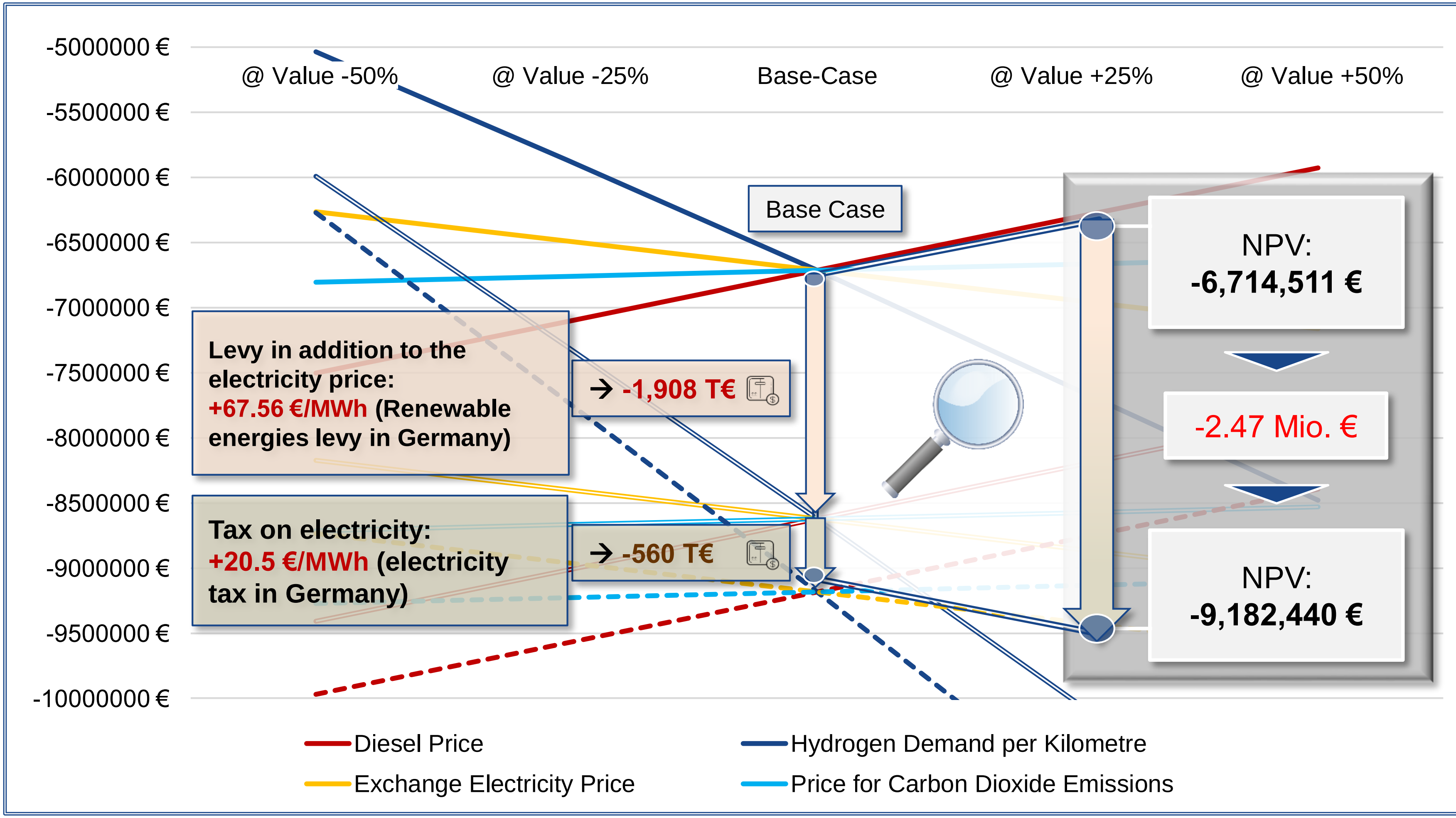

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Conclusion
Outlook and Discussion

- The studies show that there are **two very important factors**, **electricity costs** and **funding programmes** (funding rates), which have a **significant influence** on the result of the **economic efficiency calculation**!
- In particular, the results and outcomes from the **National Hydrogen Strategy** and the **roadmaps** of the individual federal states will **significantly influence** the dynamics of the **expansion** of **electrolysis capacity**!
- Great **potential** for achieving **high efficiencies** (up to 80%) is attributed to **high-temperature electrolysis** (SOEC electrolyser)!
- The **combination** of **utilisation paths** for the products **hydrogen, oxygen** and **heat** offers great potential for **optimising the economic efficiency of water electrolysis, taking into account the site-specific parameters**.

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Feel free to ask questions and make comments!

Thank you for your Attention!

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