



**BEE**  
BEV Goes eHighway



**BEE**  
**Final Event**  
**RWTH Aachen**  
**09.12.2025**



**BEE**  
BEV Goes eHighway



**Welcome**  
**Prof. Lutz Eckstein**  
**Prof. Achim Kampker**  
**RWTH Aachen**



### Institute for Automotive Engineering (ika)

- Founded in 1902 (ika)
- 200 employees
- 70 engineers, 50 workers and apprentices, ~80 working students
- Cooperation partner: fka GmbH



### RWTH Aachen University

- Founded in 1870
- One of eleven universities of excellence
- > 10.000 employees
- > 44.000 students
- 70+ institutes in mechanical engineering

**RWTHAACHEN**  
**UNIVERSITY**



### Production Engineering of E-Mobility Components (PEM)

- Founded in 2014
- 200 employees
- 71 researchers, 30 workers, 100+ working students
- Cooperation partners: PEM Motion & Moion

Vehicle Domains



**Vehicle Concepts & HMI**



**Vehicle Dynamics & Acoustics**



**Energy & Powertrain Systems**



**Vehicle Intelligence & Automated Driving**



**Traffic Psychology & Acceptance**

We develop sustainable, safe and innovative mobility

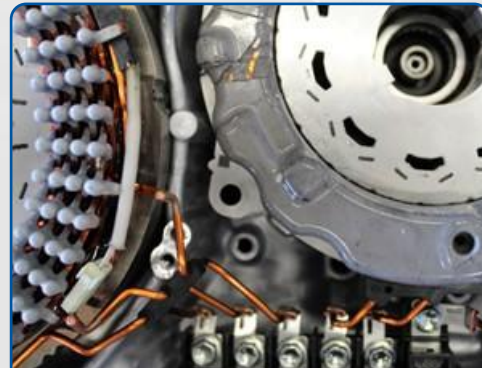


We focus on vehicles systems from micromobility to heavy-duty applications

Key Components



Battery



Electric Drive



Fuel Cell

Integration



Commercial Vehicles

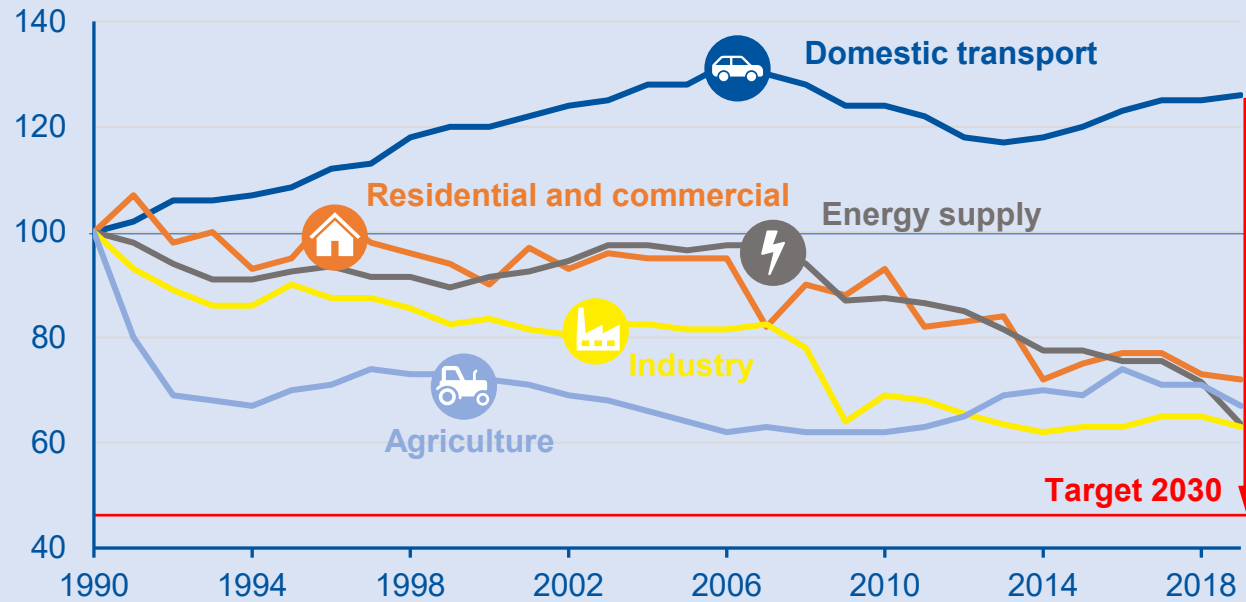
We develop pioneering products for the sustainable manufacturing of electrified powertrains



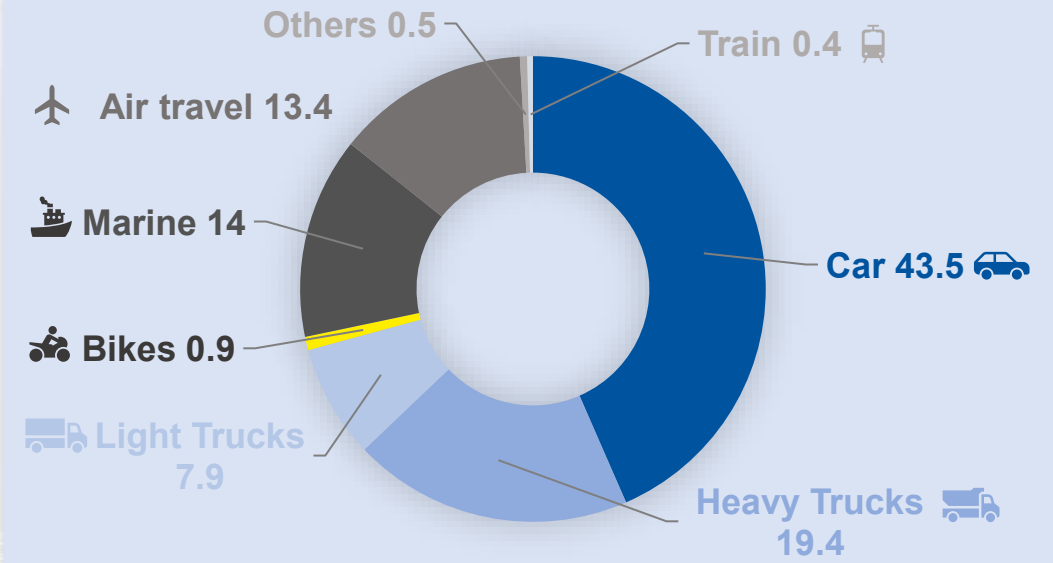
We focus on production processes and innovations that enable the cost-efficient realization of these products

# Emissions in Transport

## Emissions in the EU by Sectors



## Transport Emissions by Vehicle



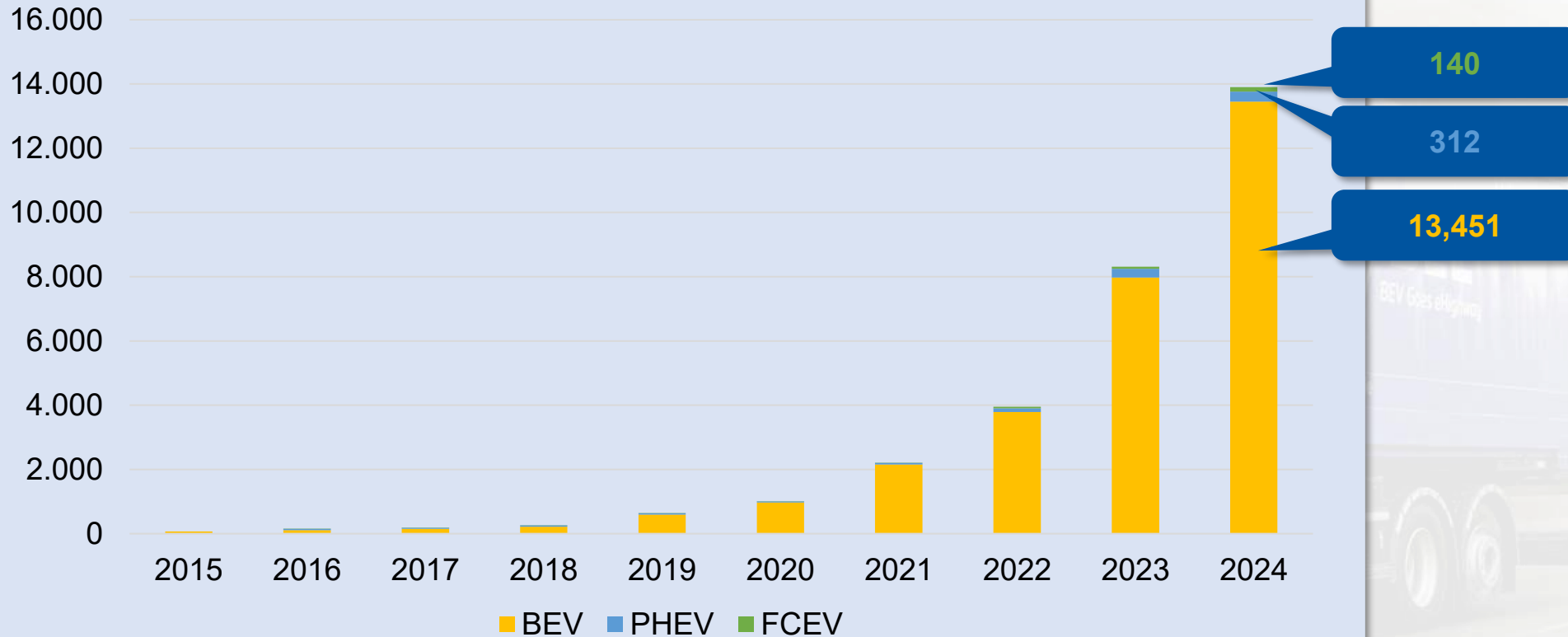
The EU aims to reduce all emissions from 1990 levels by 55 % until 2030. In contrast, the transport sector has increased its emissions by 25 %



Heavy-duty trucks contribute substantially to transport emissions. Broad adoption of alternative powertrain technologies is essential for reductions.

# Progress of Zero Emission Trucks

Heavy-duty trucks with alternative powertrains in EU



VS.

~484,000 new trucks in 2025

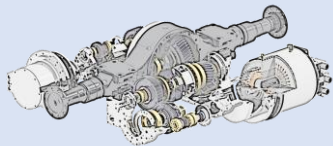
Alternative powertrains for heavy-duty trucks have achieved low market penetration. Cost-effective and easy to adapt solutions are necessary.

## Concept ELV<sup>2</sup>



*Research on an innovative and more efficient e-axle concept for heavy distribution traffic*

- **Application scenario:** Urban distribution traffic
- **Gross weight:** 26 t – 41 t
- **Research focus:** Battery-electric powertrain, user interaction, requirements of urban distribution traffic



## ESCALATE



*Powering EU Net Zero Future by Escalating Zero Emission HDVs and Logistic Intelligence*

- **Application scenario:** Regional & Long-haul
- **Gross weight:** 20 t – 44 t
- **Research focus:** Zero emission trucks, powertrain development, fleet management, digital twin



## eTestHiL



*Development of test methods for electrified heavy-duty powertrains for standardisation based on multi-physical hardware-in-the-loop test benches*

- **Application scenario:** Long-haul
- **Gross weight:** 42 t
- **Research focus:** Purpose-designed electric drive axle with application-specific suspension system

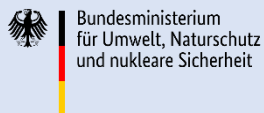


## LiVe



*Lifecycle cost reduction in electrical distribution transport by means of an adaptable drivetrain*

- **Application scenario:** Urban distribution traffic
- **Gross weight:** 7.5 t – 18 t
- **Research focus:** Battery-electric, hydrogen and pantograph-based powertrains

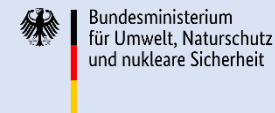


## LiVePLuS



*Life cycle cost reduction in electrical distribution traffic through catenary trolley based electrification systems for tractor units*

- **Application scenario:** Urban distribution traffic
- **Gross weight:** Long-haul
- **Research focus:** Pantograph-based tractor unit



## SeLv



*Heavy goods vehicles for emission-free logistics in heavy goods traffic by means of an electrification kit and economical production system*

- **Application scenario:** Long-haul
- **Gross weight:** 42 t
- **Research focus:** Hydrogen powertrain



Gefördert durch:



Koordiniert durch:



# Road to Sustainable Transport



# Road to Sustainable Transport



# Thank you for your attention!



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**Greetings  
from Project  
Administration  
Maximilian Heckert  
VDI/VDE**



**BEE**  
BEV Goes eHighway



# Project Overview

Gordon Witham  
RWTH Aachen

# Motivation



© FuE-Zentrum FH Kiel



© dpa



© Siemens

# The BEE Project

## Project idea

Retrofitting series BEV trucks with pantograph system and testing in field trials

- 1 university
- 2 prototypes
- 4 test tracks



## Associated partners:

**CONTARGO®**  
 ■■■ trimodal network

**DAF**

**DSL** Bundesverband  
 Spedition und Logistik

**MERCK**

**RHENUS**  
 LOGISTICS

**SIEMENS**

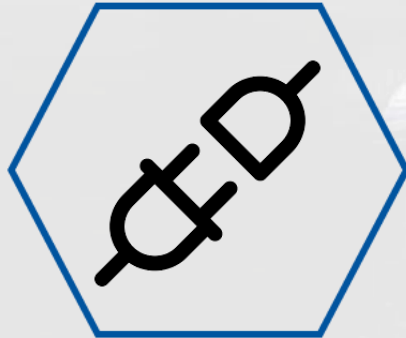
Supported by:

 Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety

based on a decision of the German Bundestag

 Erneuerbar mobil

# Project Goals



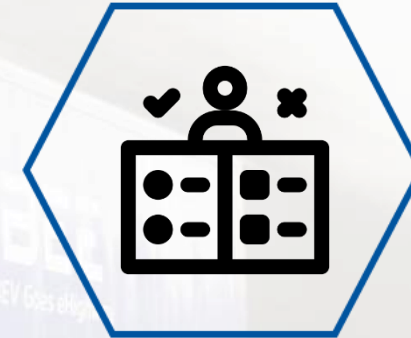
## Interface development

Development of a system interface for the standardized integration of overhead line technology together with vehicle and component manufacturers



## Road testing

Test drives on public roads with vehicles of different powertrain technologies for direct technology comparison



## Technology assessment

User studies with drivers from the logistics industry, evaluation of stakeholder input and validation with gathered data from prototypes

# Project Kickoff



**April 2022**  
Project kickoff in Aachen

# DAF joins the Project



**December 2022**  
DAF joins the project as  
associated partner

# First Deliveries



**March 2023**  
Pantographs and the  
first vehicle arrive

# Mechanical Mockup Complete



**September 2023**  
Design, construction and  
integration of mechanical  
mockup completed

# Electric Trucks Assembled



**December 2023**  
Electric trucks were  
assembled and handed  
over to RWTH

► **Duitse test met DAF-trucks aan bovenleiding mogelijk ook in Nederland**

# DAF straks aan een draad

Een elektrische truck die, zoals een trein, tram of bus is verbonden aan een bovenleidingsysteem om tijdens de rit stroom te laden.

**Peter Scholtes**  
peter.scholtes@ed.nl  
Eindhoven

Het Duitse Institut für Kraftfahrzeuge (Ika) onderzoekt samen met DAF of het systeem met bovenleidingen bijdraagt in de energietransitie.

Twee elektrische DAF's heeft het Duitse onderzoeksinstituut in ontvangst genomen. De trucks worden voorzien van een pantograaf, een stroomafnemer die wordt gekoppeld aan een bovenleidingsysteem.

'In theorie heeft zo'n truck een aantal voordelen: het voertuig laadt tijdens het rijden op en kan daardoor met een kleiner batterijpakket toe', laat DAF weten. 'Dat drukt onder meer de kosten, vergroot het laadvermogen en voorkomt laadpauzes. De test moet uitwijzen of de truck met pantograaf inderdaad een bijdrage kan leveren aan de energietransitie, of dat ook in praktische zin een haalbare oplossing kan zijn en voor welke inzet.'



▲ Roland Uerlich en Gordon Witham van het Duitse onderzoeksinstituut Ika nemen de twee elektrische DAF's in ontvangst in Eindhoven.

FOTO IKA

**December 2023**  
Electric trucks were assembled and handed over to RWTH

# First Electric Truck Delivered



**June 2024**  
First electric truck  
delivered to Aachen,  
beginning of retrofit

# Testing of Electrical Interface



**July 2024**  
First tests charging  
directly via ePTO  
interface, then via  
pantograph

# Testing on Siemens Test Track



**August 2024**  
Testing and  
commissioning of retrofit  
system on Siemens test  
track in Groß Dölln,  
presentation to  
consortium

# Testing on Siemens Test Track



**August 2024**  
Testing and  
commissioning of retrofit  
system on Siemens test  
track in Groß Dölln,  
presentation of “Maja”  
to consortium

# EMC Testing



**September 2024**  
EMC testing of full  
vehicle with pantograph  
according to ECE R10

# Road License



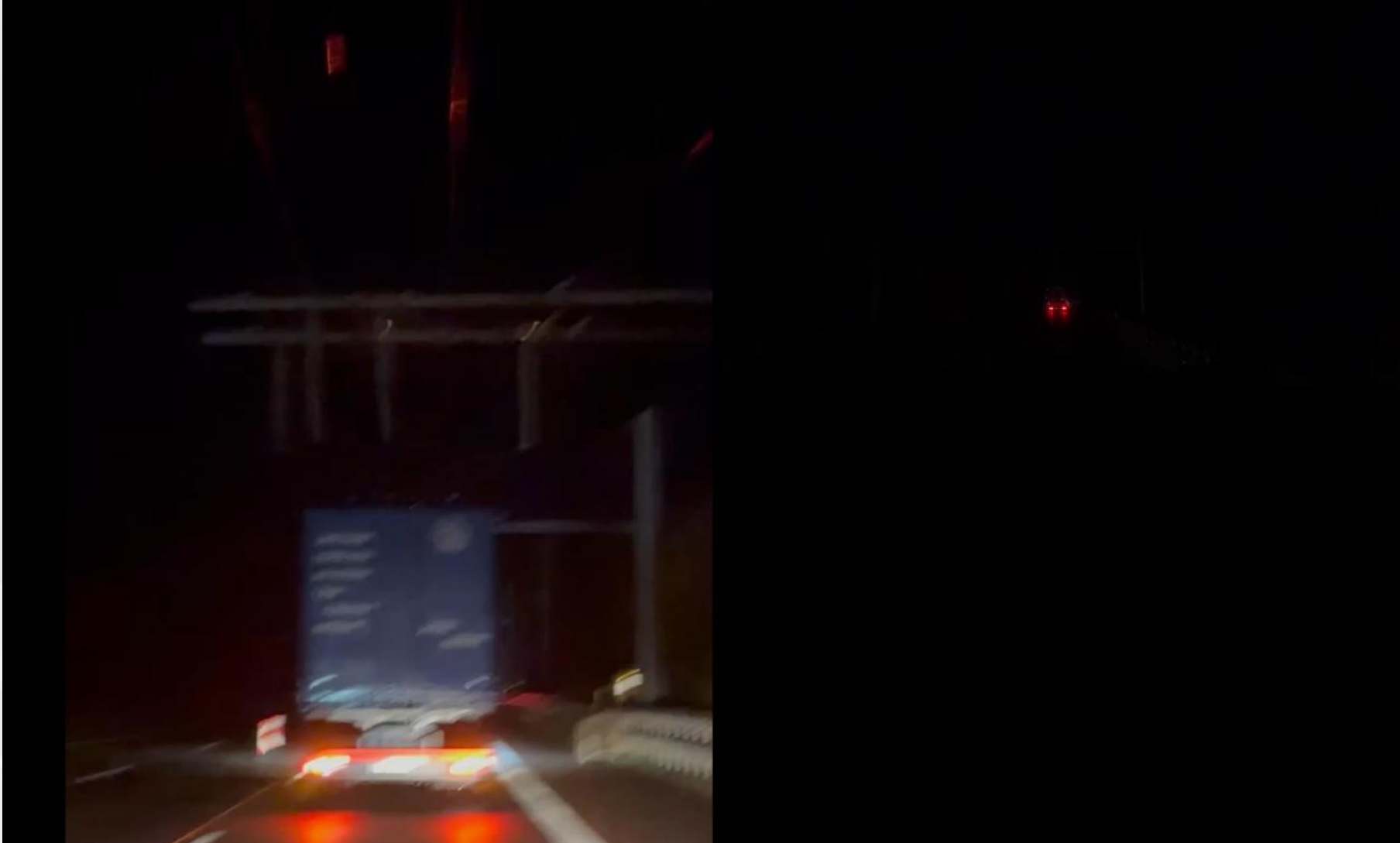
**November 2024**  
Both vehicles receive a  
road license by change  
approval

# Commissioning and Testing at FESH



**November 2024**  
Commissioning of “Willi”  
on closed lane of A1 in  
FESH test track at night,  
first test drives on public  
roads

# Commissioning and Testing at FESH



**November 2024**  
Commissioning of “Willi”  
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# Commissioning and Testing at FESH



**November 2024**  
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# Test Drives at ELISA and eWayBW

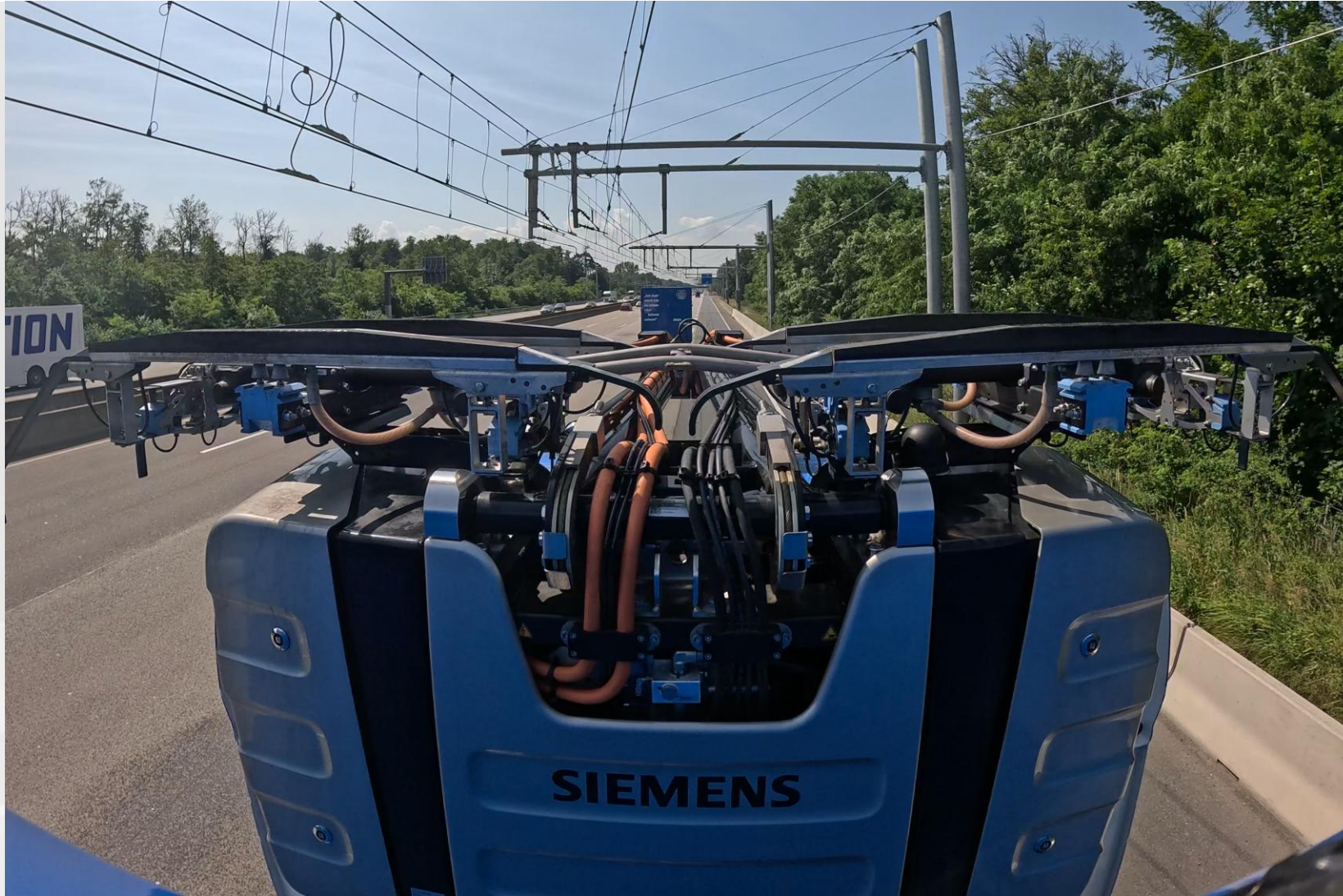


© Die Autobahn GmbH des Bundes

**November & December  
2024**

Test drives at ELISA and  
eWayBW under cold  
conditions

# Test Drives at ELISA



**June 2025**

Test drives at under warm conditions after optimizations and implementation of additional measurement equipment

# A reminder, why ERS make sense...



# A reminder, why ERS make sense...



# A reminder, why ERS make sense...



# A reminder, why ERS make sense...



# A reminder, why ERS make sense...



# A reminder, why ERS make sense...



# A reminder, why ERS make sense...



# Thank you for your attention!

**ika**

**RWTHAACHEN**  
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**eHighway ready**

**Clemens Niederée**

**RWTH Aachen**

# BEV Goes eHighway



Pantograph as a pivotal component of the vehicle's drivetrain



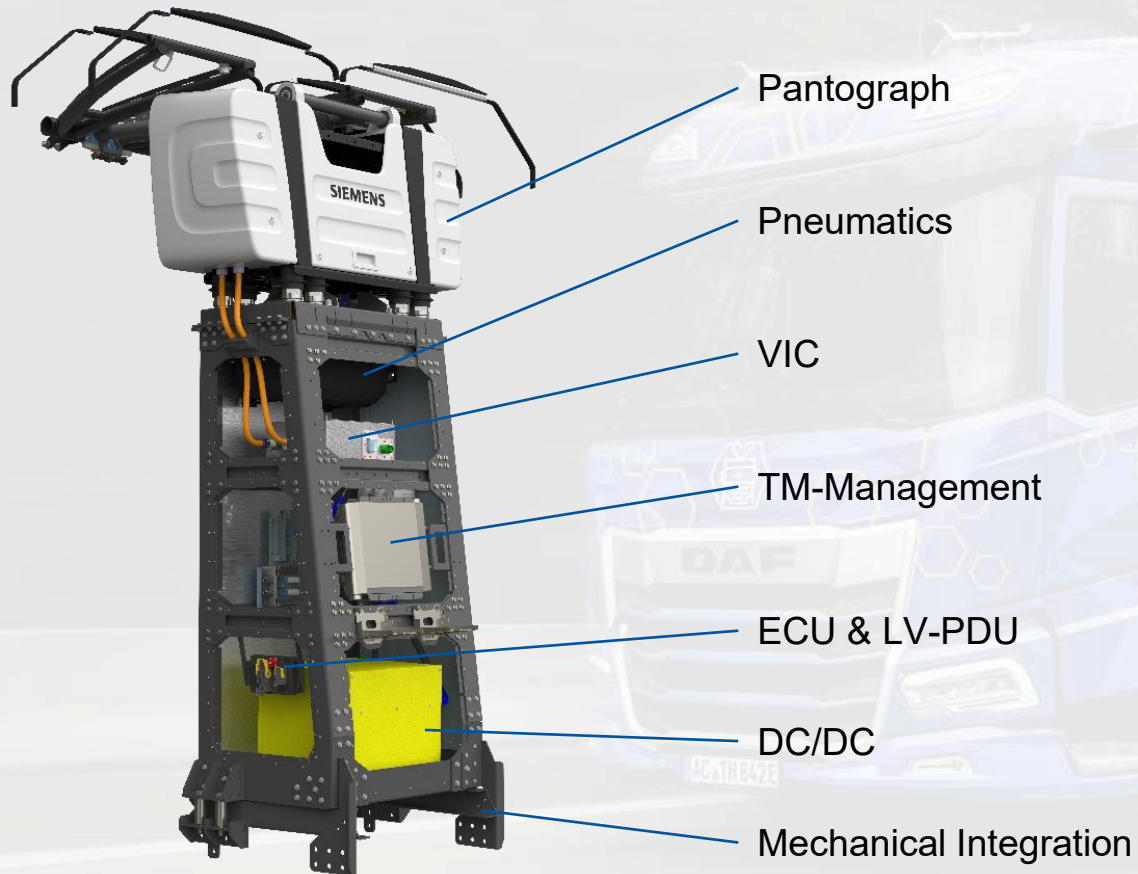
Base vehicle extended by a pantograph as a range extender

Development of a retrofit solution for a pantograph system to use with a standard battery electric truck. Derive a "eHighway ready" standard.

# System Overview



# System Overview




## BEEone – Maja

- DC/DC Schäfer K2243
- 540...730 VDC
- 0...54 A
- $P_{out} = 35 \text{ kW}$
- $\eta = 90 \%$
- $Q_A = 3.51 \text{ kW}$
- $T_{in} = 55^\circ\text{C}$
- Mass = 70 kg
- Width = 450 mm

## BEEtwo – Willi


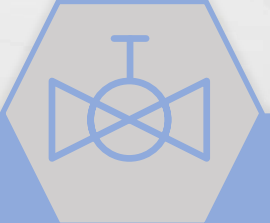
- Schäfer K2251
- 540...790 VDC
- 0...125 A
- $P_{out} = 100 \text{ kW}$
- $\eta = 95 \%$
- $Q_A = 4.05 \text{ kW}$
- $T_{in} = 40^\circ\text{C}$
- Mass = 140 kg
- Width = 850 mm

# Four Pillars of Standardisation

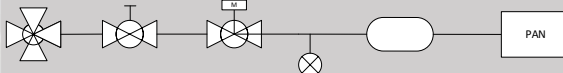

## Mechanical

- Mounting according to Body Builder guide
- Modular and adaptable to different frame geometries
- Meeting Regulations Requirements

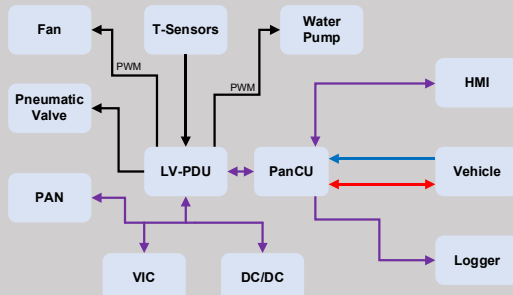

## Pneumatic

- Connected to auxiliary circuit of compressed air system
- Disconnection of compressed air system via LV-connection as a safety function
- Required filling times must be met
- Air quality must comply with the PAN manufacturer's specifications

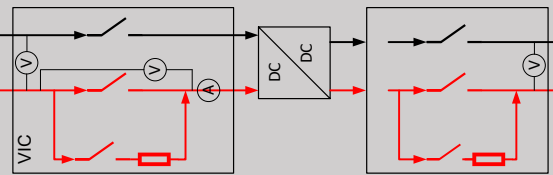
## Communication

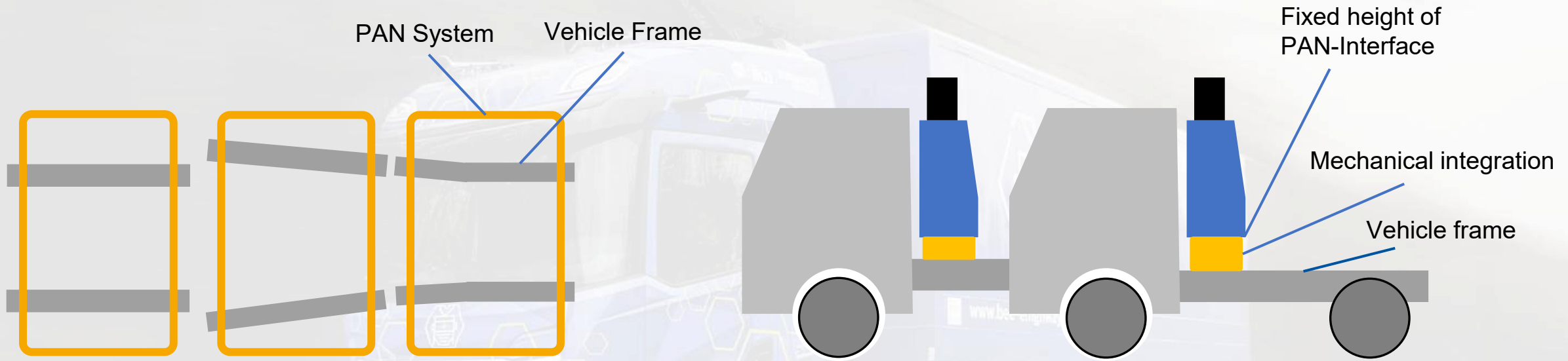
- HV-system information via BB-CAN
- Active communication with vehicle via BB-CAN
- PAN tower has its own ECU

## Electric

- Connection to HV system via ePTO
- Interface must function bi-directional
- Limiting factor for power
- Sufficient LV-supply for PAN components





Adapting to:

Different frame widths

Different frame shapes

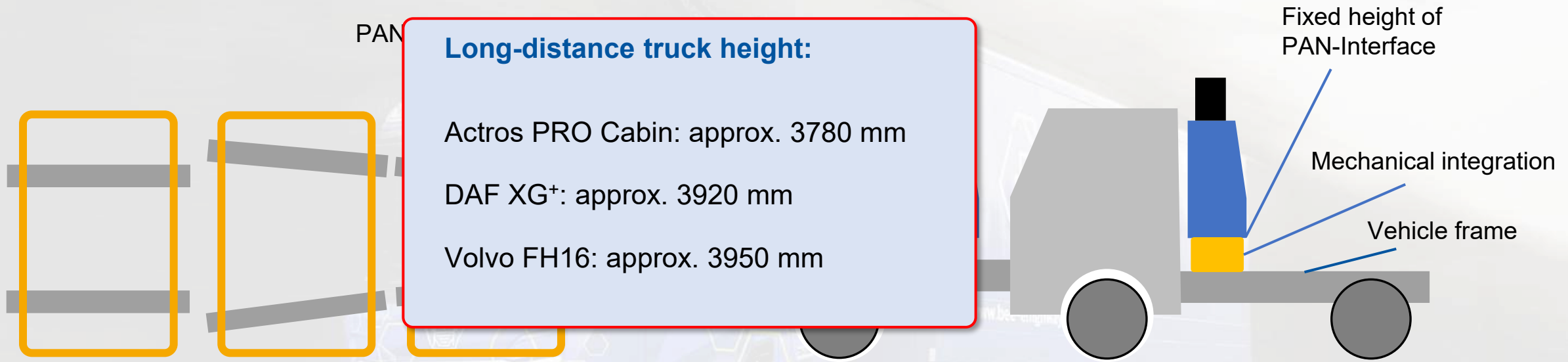
Tolerances in frame width and shape

PAN must be at set height

*Mounting needs to adapt to different frame heights*

Max. cabin height: approx.: 3650 mm

Additional 700 mm of space behind Cabin



Adapting to:

- Different frame widths
- Different frame shapes

Tolerances in frame width and shape

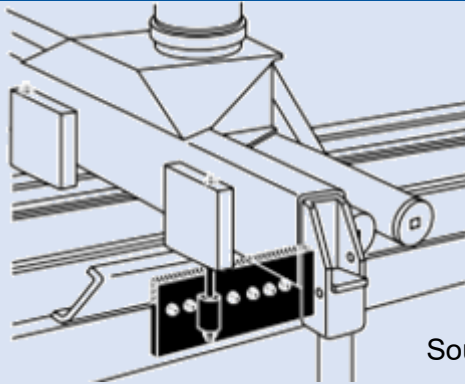
PAN must be at set height

*Mounting needs to adapt to different frame heights*

Max. cabin height: approx.: 3650 mm

Additional 700 mm of space behind Cabin

## Crane Mounting



Source: DAF

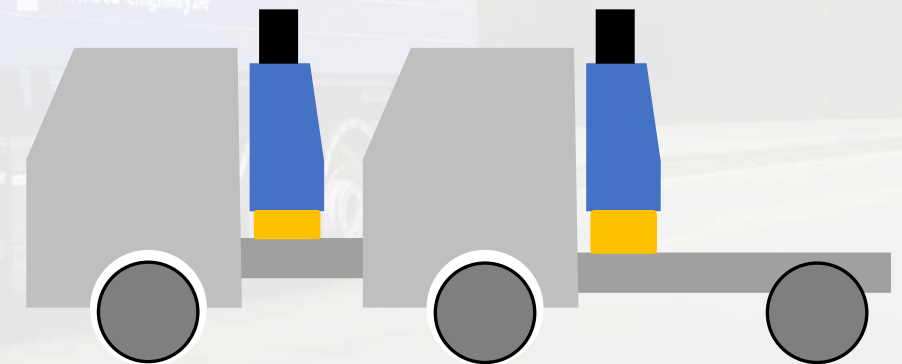


### Adapting Mounting Concept of the Loading Cranes

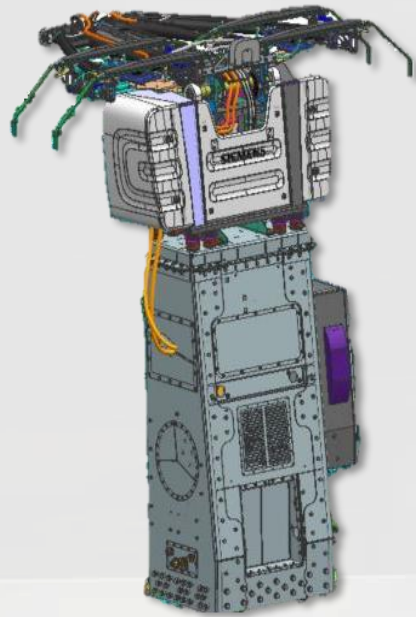
- Same mounting space behind the cabin (additional 800 mm)
- Same mounting “problem” standard crane for different vehicles
- Similar loads on the frame
- OEM consider this use case in the development
- Detailed information in the Bodybuilder Guides



Adapting to different frame widths and shapes

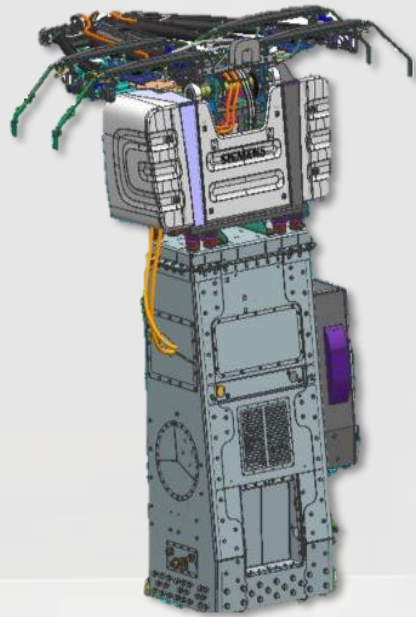


Adapting to different frame heights

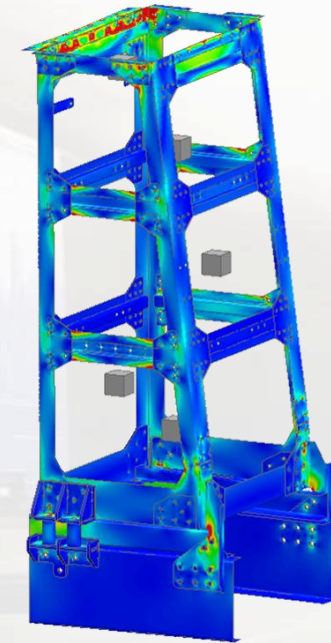


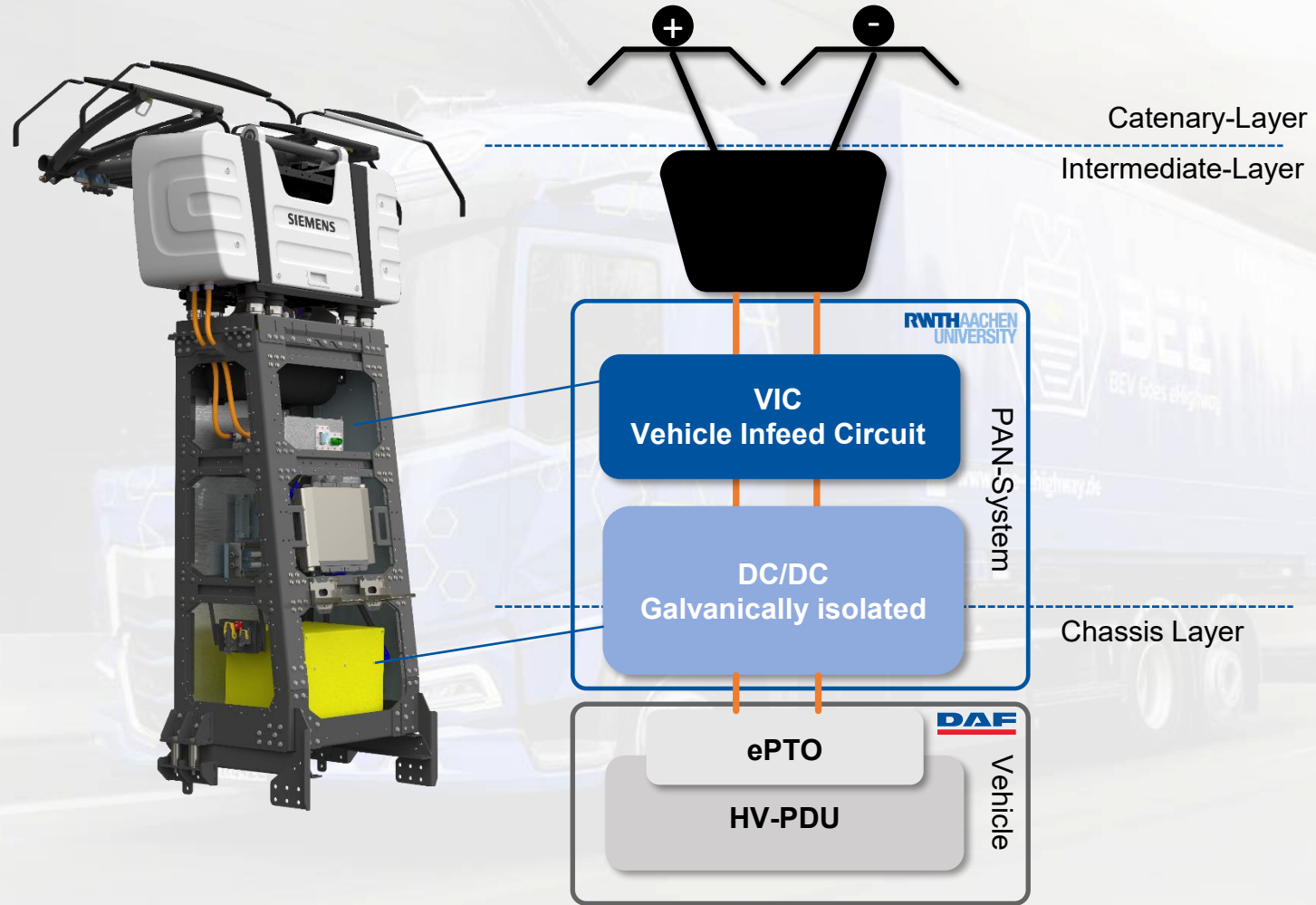
Weight reduction of 50%  
Adapted trellis frame concept  
Hatprofilis show strength and versatility  
Extended simulation and optimization process  
Improved force application and directing  
Further improvement by diagonal profiles





Weight reduction of 50%  
Adapted trellis frame concept  
Hat-profiles profile show strength and versatility  
Extended simulation and optimization process  
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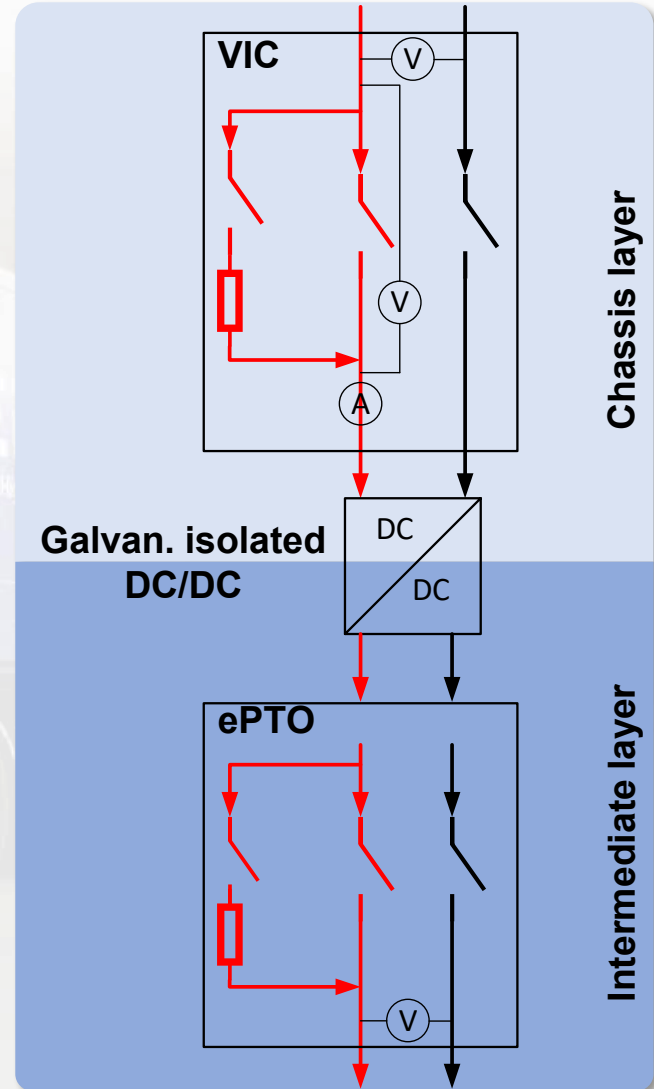
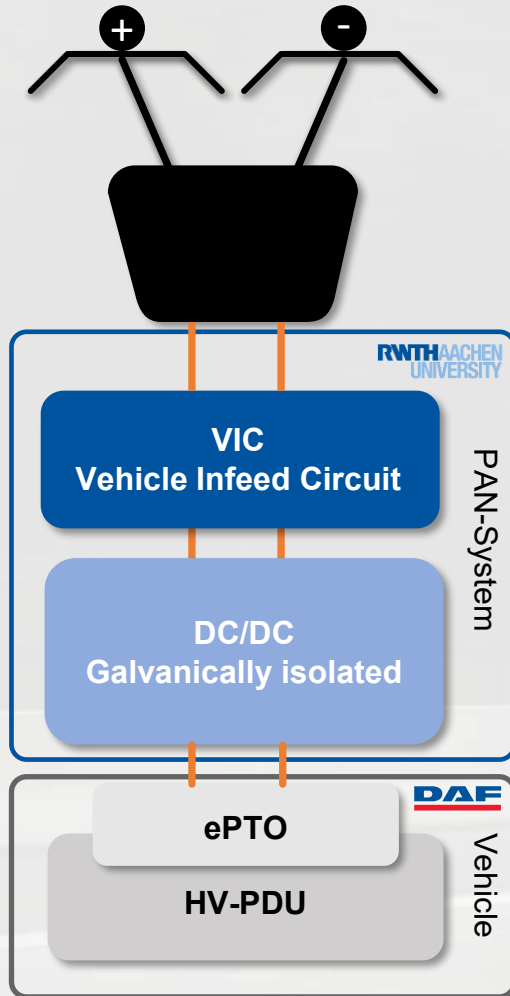


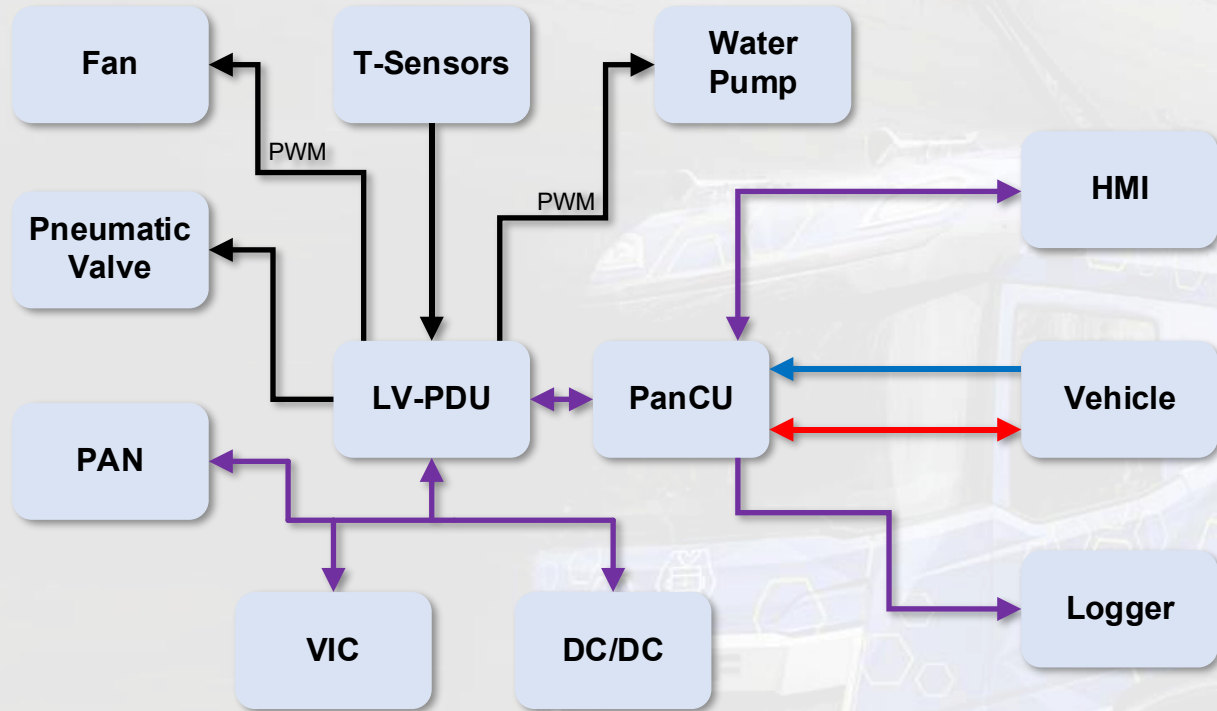
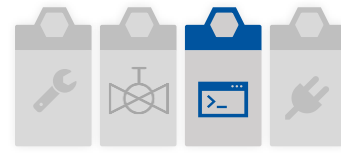
## HV connection via ePTO

- + ePTO needs to work bidirectional
- + normal HV interface of the vehicle
- + No changes to the vehicles HV system needed
- + Using the Bodybuilder-CAN to control the interface
- current power limitation of 90 kW
- Not officially approved to be used bidirectional

## Galvanically isolated DC/DC Converter

- + Additional safety layer
- + Charging while stationary
- Current DC/DC converter limited to 100 kW
- High costs and weight for the DC/DC
- When the ePTO power limitation is solved a non-isolated DCDC becomes more interesting





## Communication

### Isolation Measurement

- PAN and Vehicle measurement might interfere
- Vehicle must enable a handshake protocol for isolation measurements

### HV System Status

- Detailed Status of the HV System need to be communicated via the BB-CAN
- Voltage Level
- Possible charging current

#### BB CAN

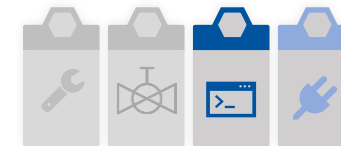
- ePTO control
- ePTO status
- Vehicle driving status

#### P CAN

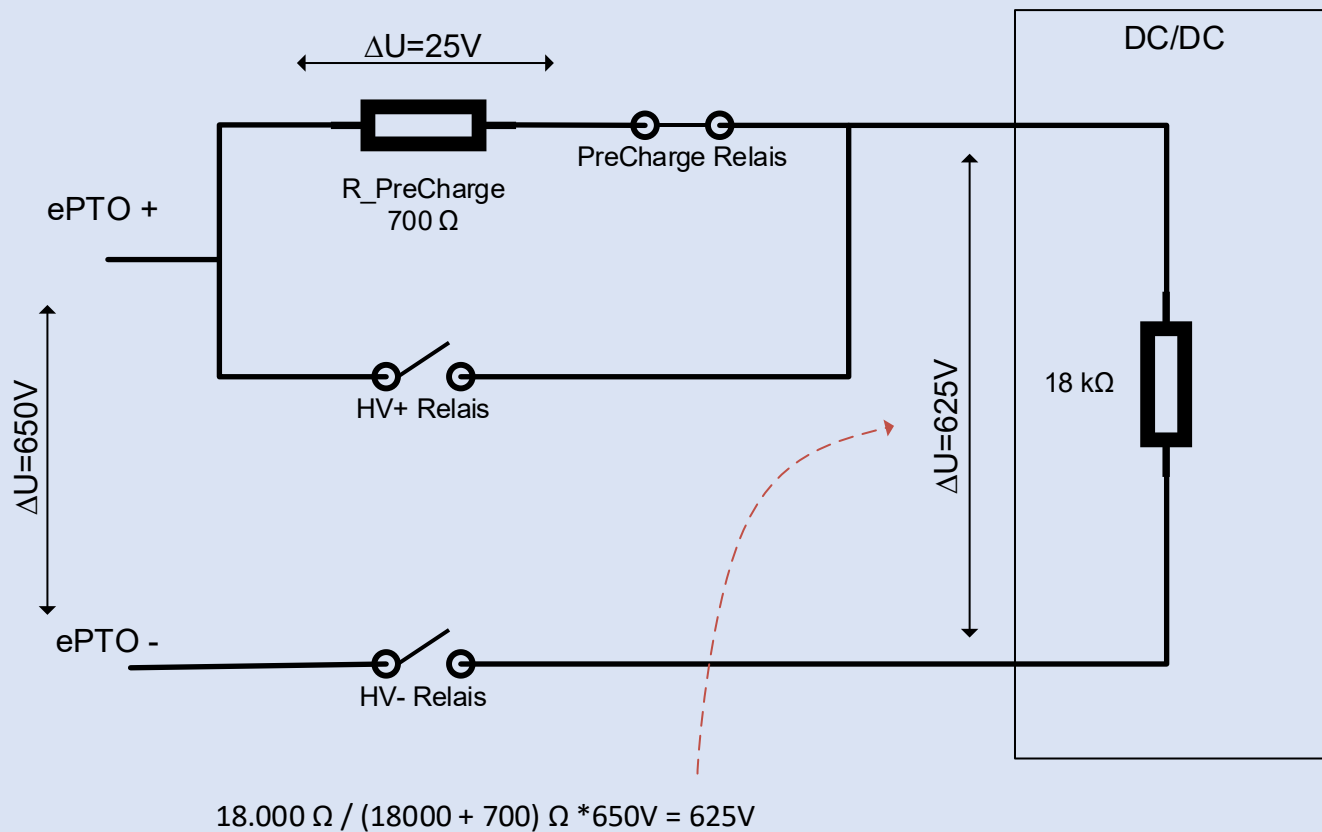
- Voltage Levels
- Charging Power
- DC/DC status & control
- TM status & control

#### Vehicle CAN

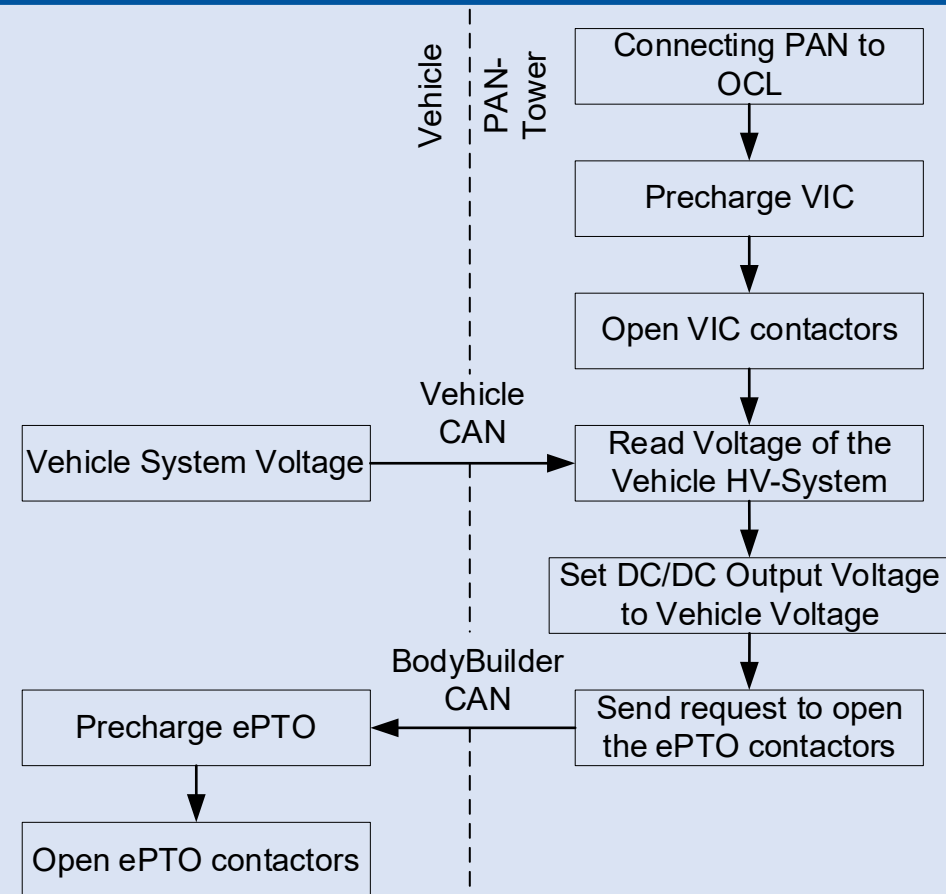
- Voltage Level
- Battery Current limit
- HV system status



## Precharging Error

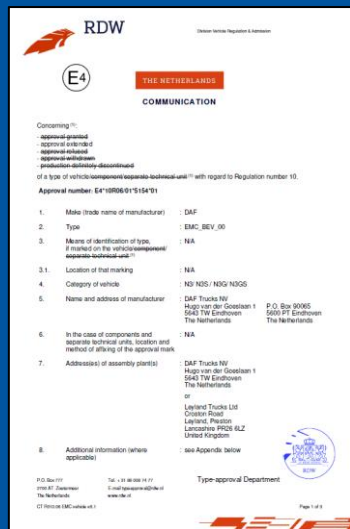


## Reversed precharging



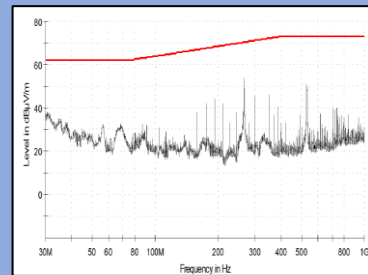
# Homologation Process

## Vehicle with Type Approval



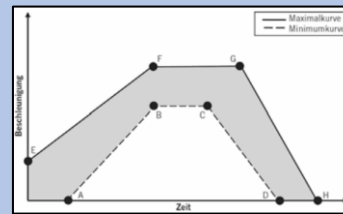
## ECE R10

- EMC Testing
- Interference immunity
- Electromagnetic emission



## Mechanical Testing

- Proof of mechanical integrity
- Proof through simulation
- ECE R100 load case



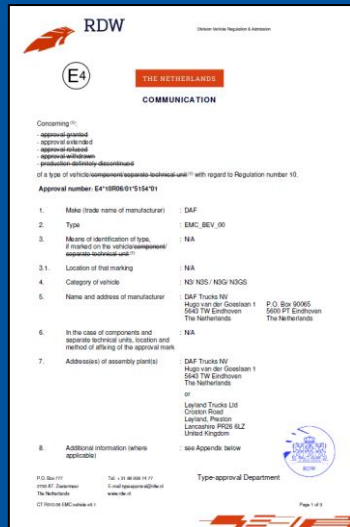
## Electric Testing

- Electric Testing for ECE R100
- Measuring equipotential
- Check of Layer concept

Individual operating permit

# EC Type Approval

## Vehicle with Type Approval



**RDW**  
 THE NETHERLANDS  
 COMMUNICATION

Concerning:  
 approval granted  
 approval refused  
 approval withdrawn  
 production certificate discontinued

of a type of vehicle/component separate technical unit with regard to Regulation number 10.

Approval number: E4\*10R06 01\*1514\*01

1. Make (trade name of manufacturer)	DAF
2. Type	EMC BEV_00
3. Means of identification of type, if marked on the vehicle/component/ separate technical unit	NA
3.1. Location of that marking	NA
4. Category of vehicle	N0 N05 / N06 N06S
5. Name and address of manufacturer	DAF Trucks BV Hugo van der Gootlaan 1 5502 TM Eindhoven The Netherlands P.O. Box 0065 5500 PT Eindhoven The Netherlands
6. In the case of components and separate technical units, location and method of affixing of the approval mark	NA
7. Address(es) of assembly plant(s)	DAF Trucks BV Hugo van der Gootlaan 1 5502 TM Eindhoven The Netherlands or Leiford Trucks Ltd Chisum Road Leiford, Pepton Lancashire PR20 6LZ United Kingdom
8. Additional information (where applicable)	see Appendix below

P.O. Box 177  
 3720 BT Driebergen  
 The Netherlands  
 www.rdw.nl

Tel. +31 36 544 14 17  
 E: contact@rdw.nl

Type-approval Department

Page 1 of 1

## EC Type Approval

- Pantograph System approved for certain vehicles
- No EMC tests
- No simulations necessary

## Electric Testing

- Electric Testing for ECE R100
- Measuring equipotential
- Check of Layer concept

**Individual operating permit**

# Thank you for your attention!



**RWTHAACHEN**  
UNIVERSITY



## **Clemens Niederée**

Production Engineering of E-Mobility Components

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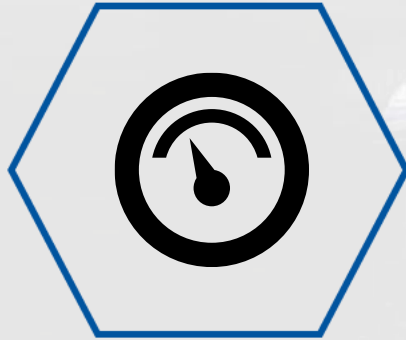


# Test Drives

Daniel Swierc  
RWTH Aachen

# Test Drives

## Workpackage Overview



### Data Measurement

- Acquire data from several sources in the vehicle
- Extract, aggregate and postprocess



### Real World Testing

- Real world testing on public roads
- Functional testing in different environmental conditions

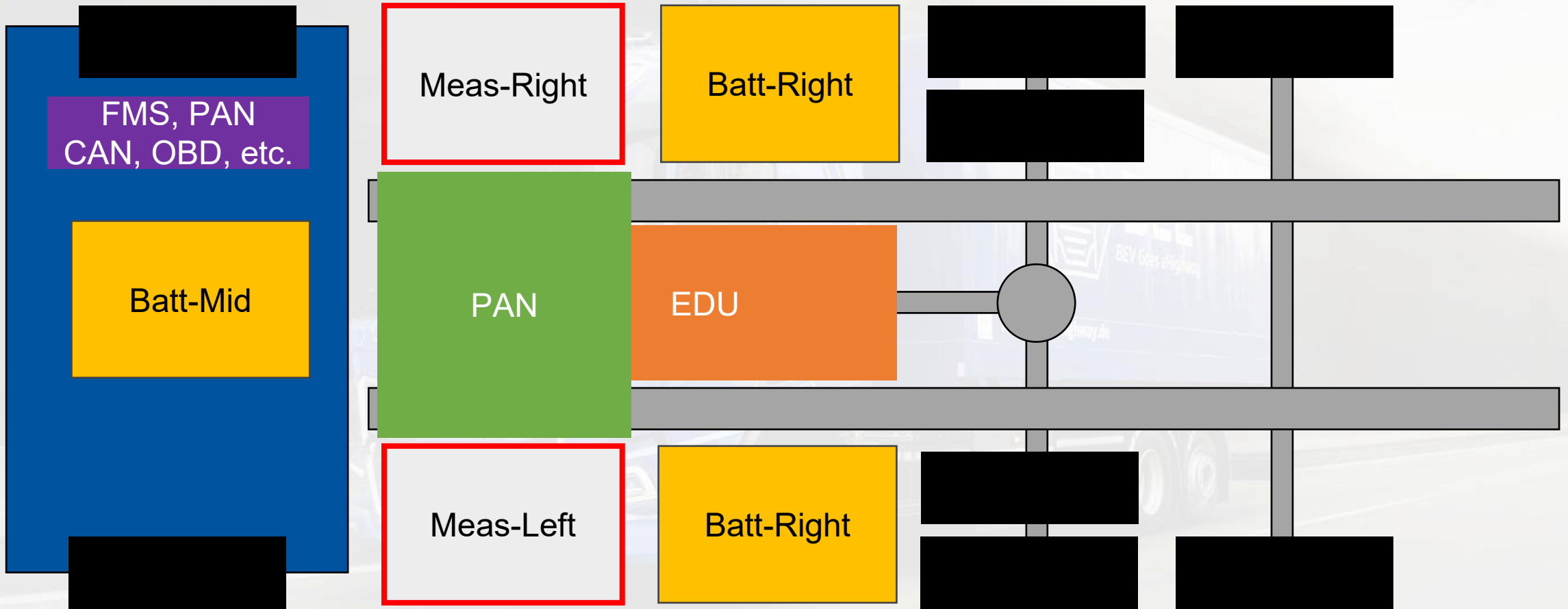


### Vehicle Modeling

- Digital Twin of the vehicle for e.g. costs and energy demand investigation
- Use measured data to improve accuracy

# Measurements

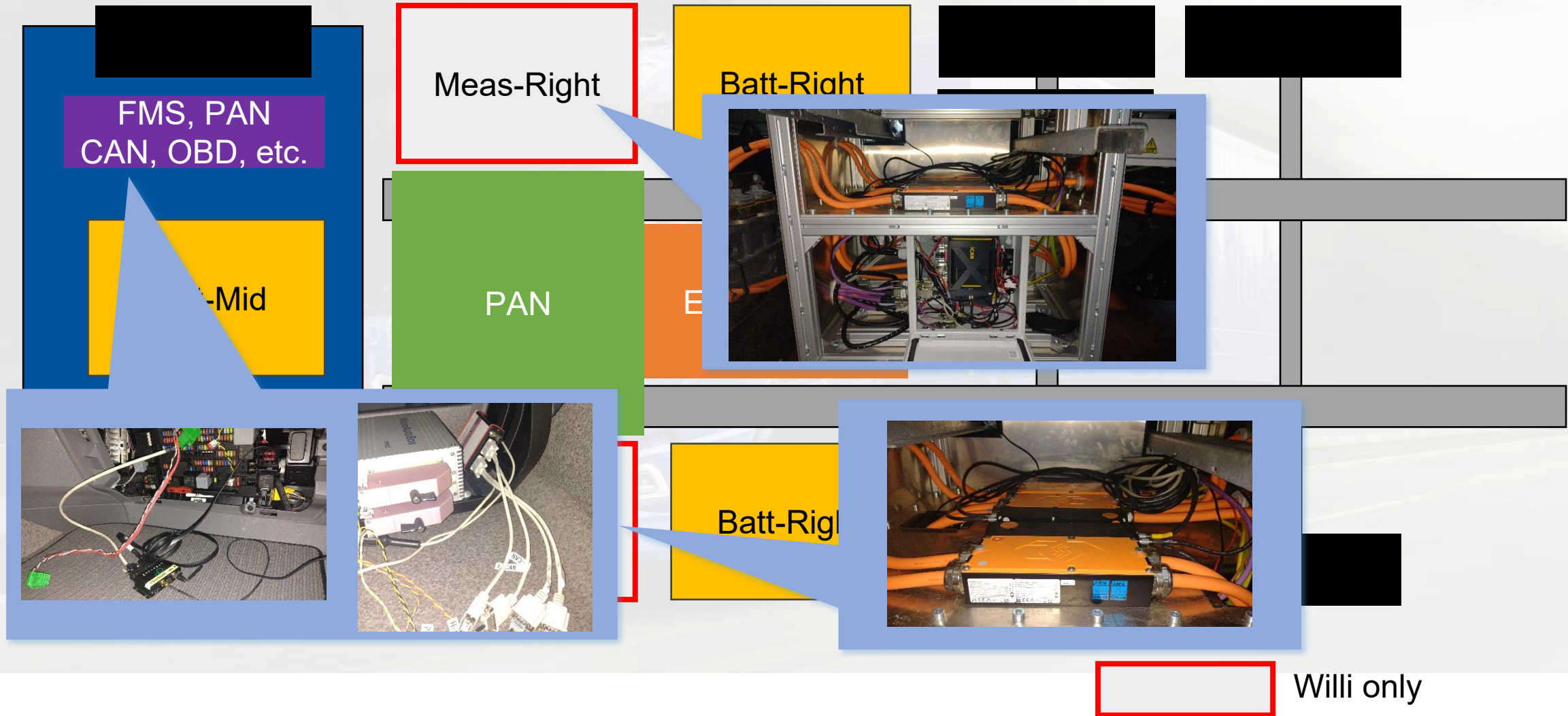
## Setup



 Willi only

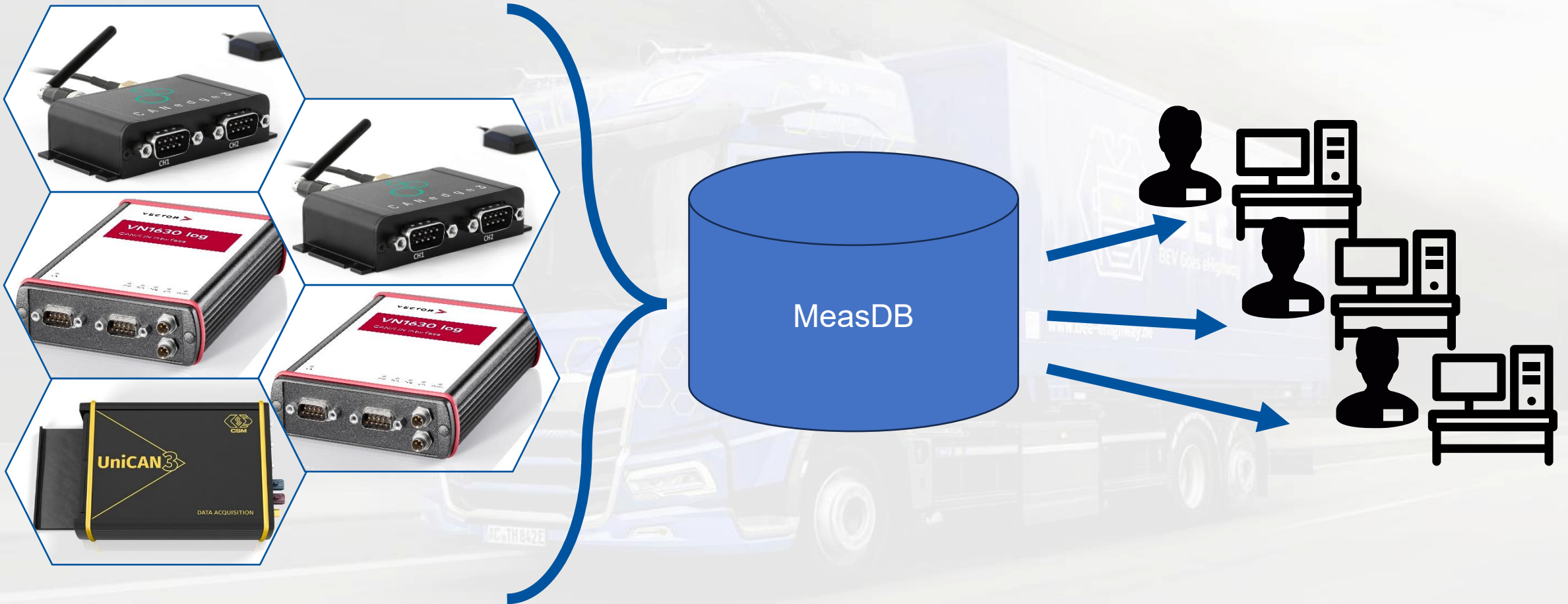
# Measurements

## Setup



# Measurements

## *Data Aggregation*



# Test Drives

## *Catenary Test Tracks*



Groß-Dölln



FESH



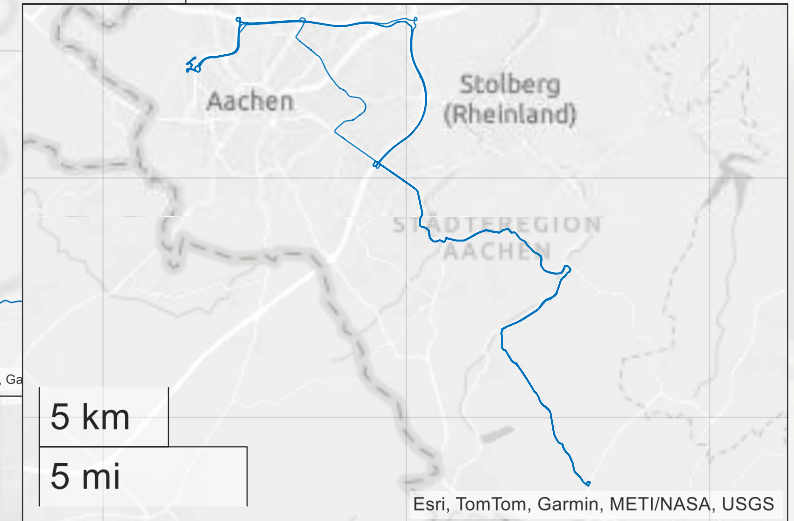
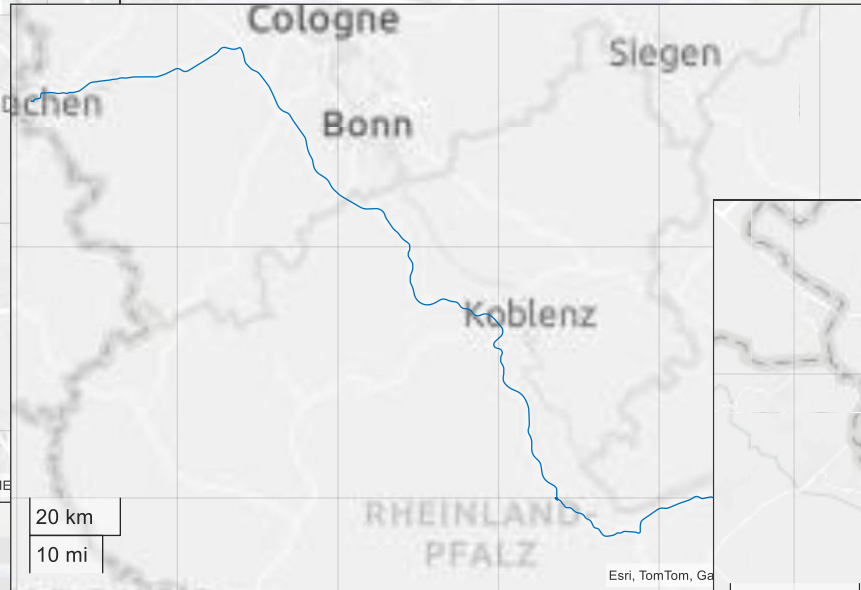
eWayBW



ELISA

# Test Drives

## *Further Routes*

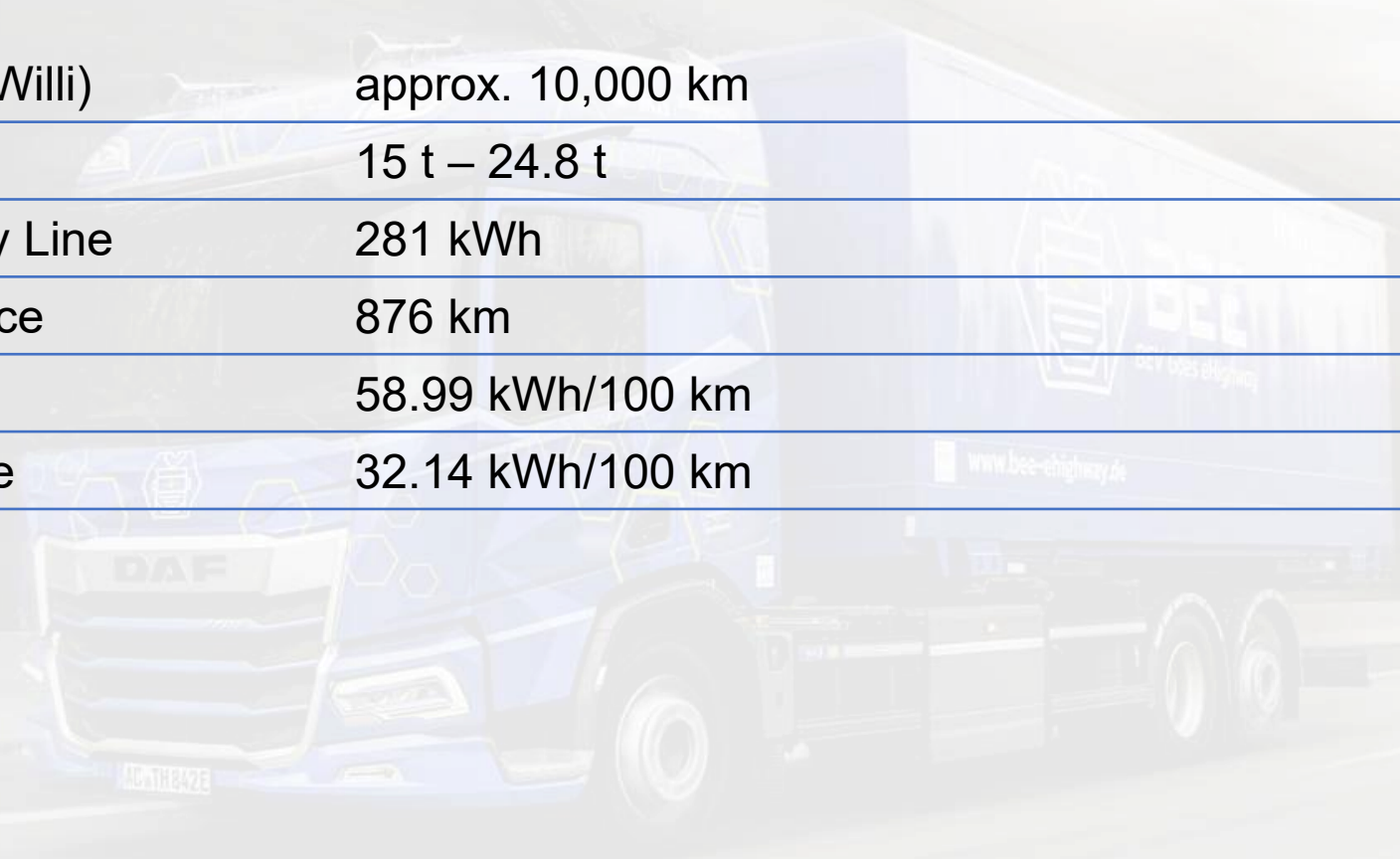


Highway/Rural

# Test Drives

## *Statistics Willi*

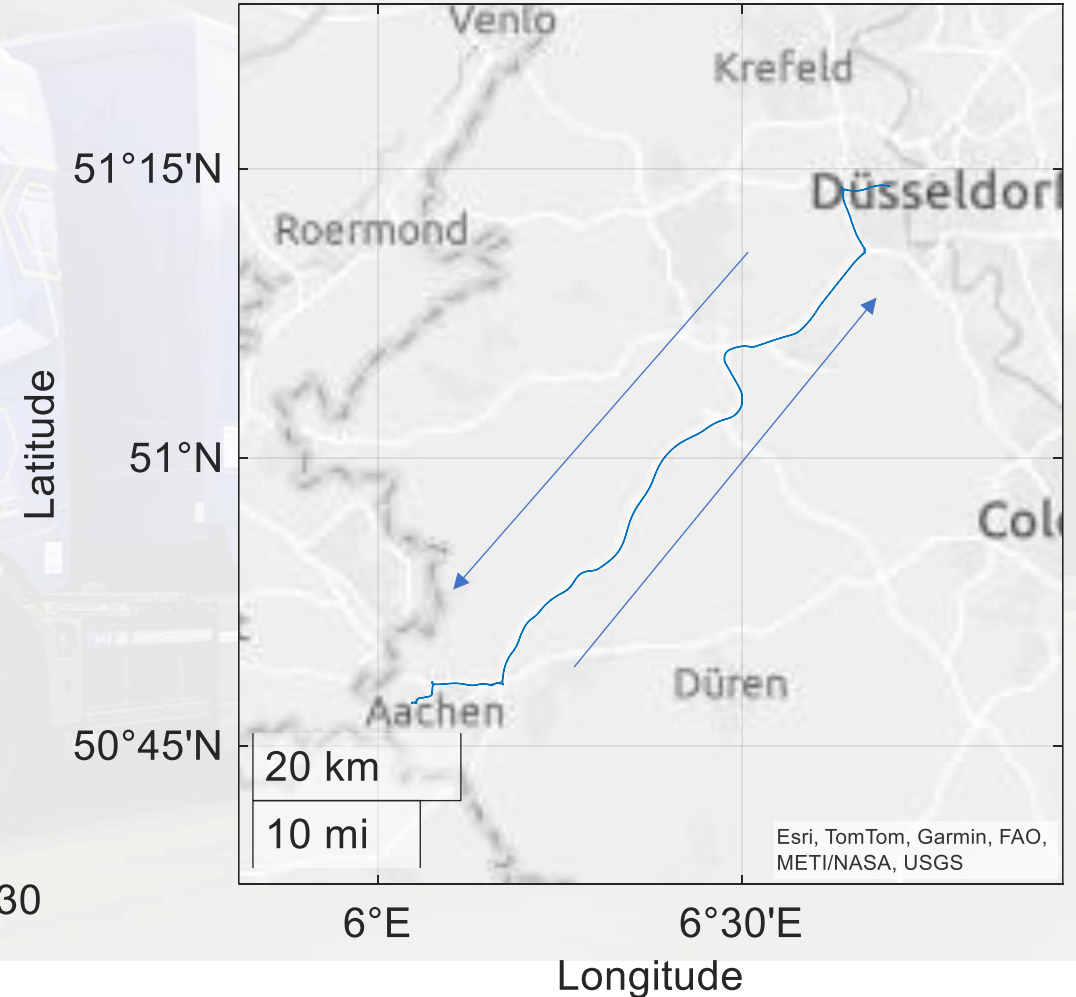
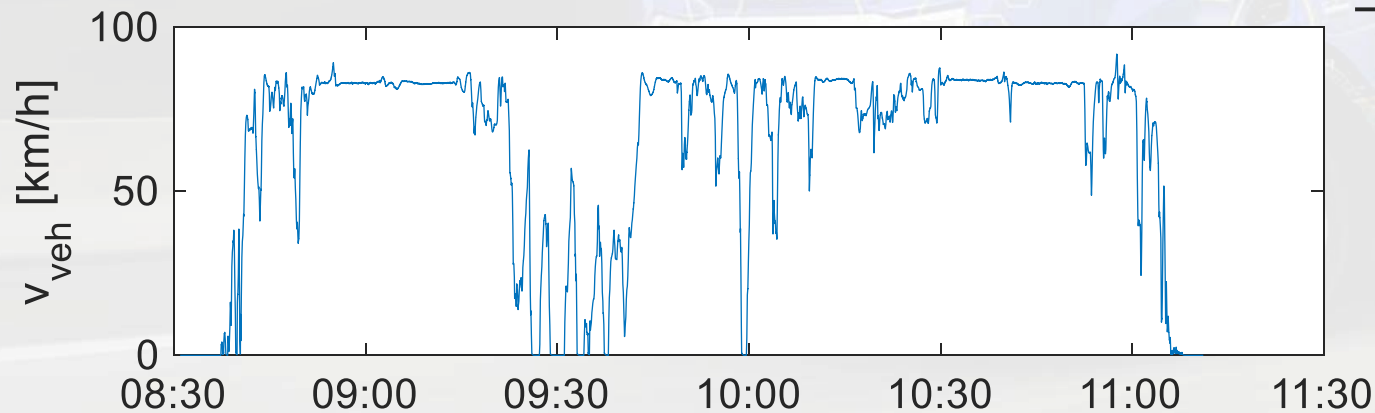
Total Distance (Maja and Willi)	approx. 10,000 km
Vehicles Weights	15 t – 24.8 t
kWh Charged on Catenary Line	281 kWh
Catenary Charging Distance	876 km
Mean Energy Demand	58.99 kWh/100 km
Mean Charge per Distance	32.14 kWh/100 km



# Test Drives

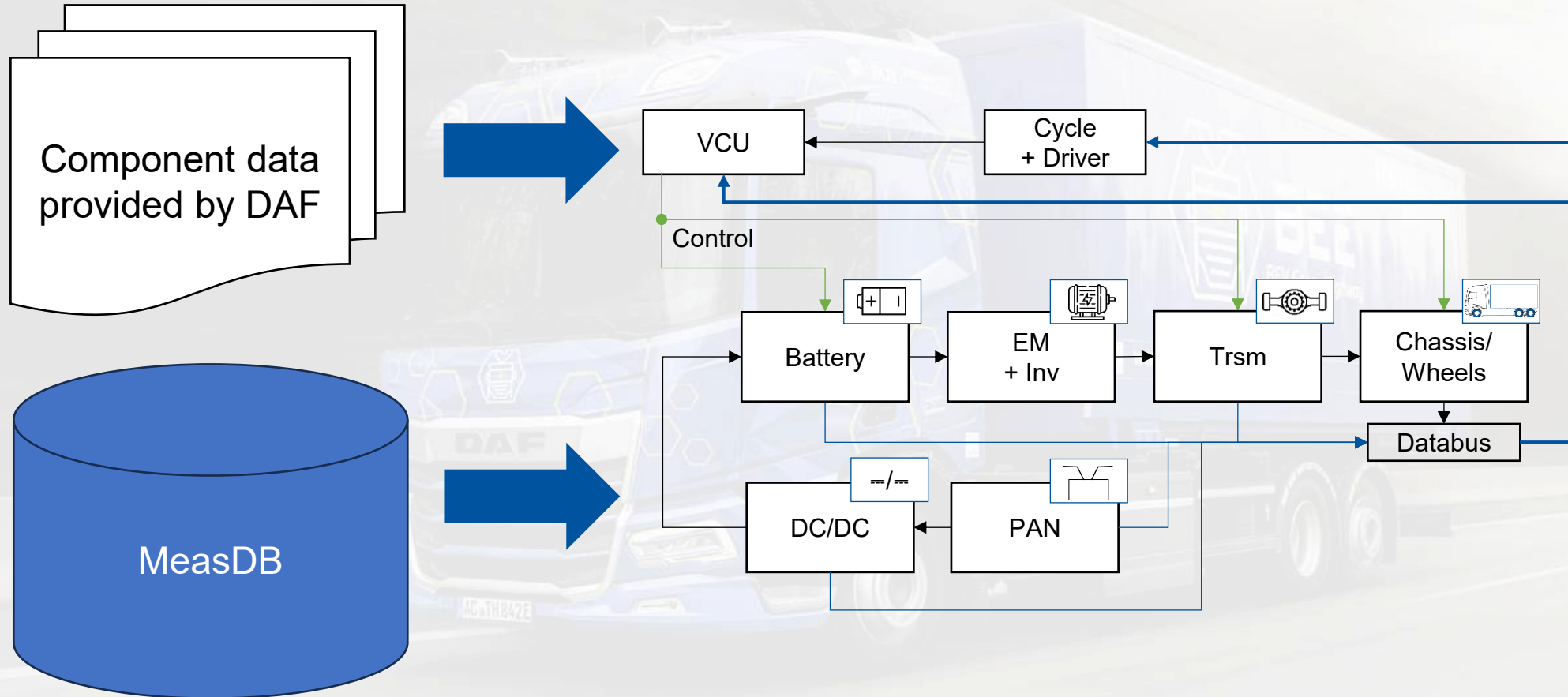
## BEV vs. Diesel - Example

Distance	ca. 170 km
Cargo Load	4 t
Energy Demand BEV	103.97 kWh (61.88 kWh/100 km)
Fuel Consumption Diesel	16.76 l/100 km (~164 kWh/100 km)



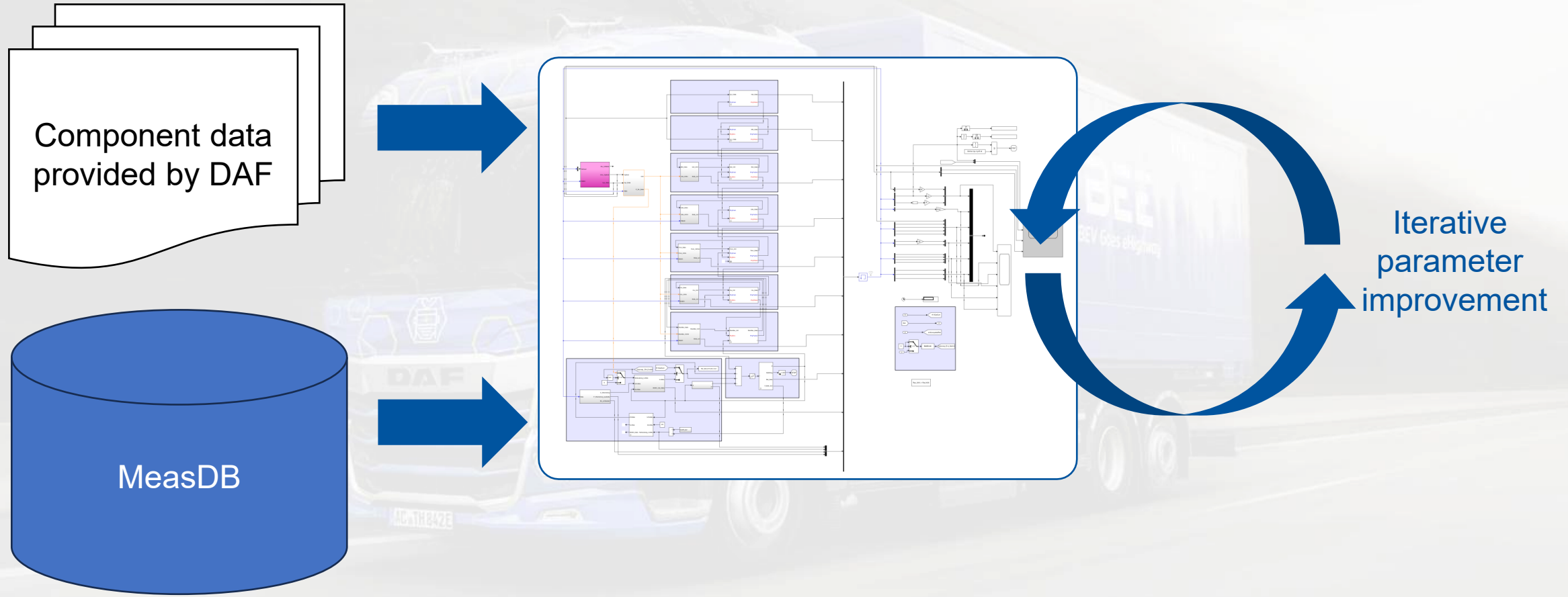
# Digital Twin

## Input Data



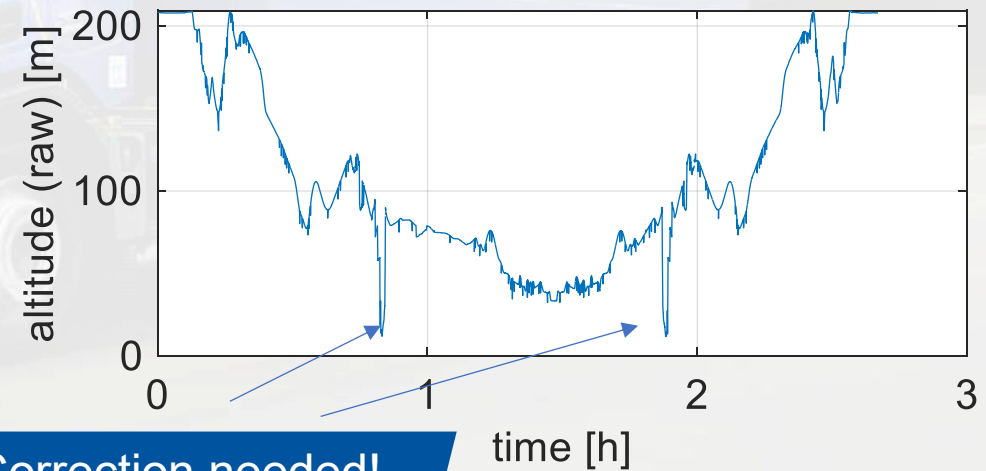
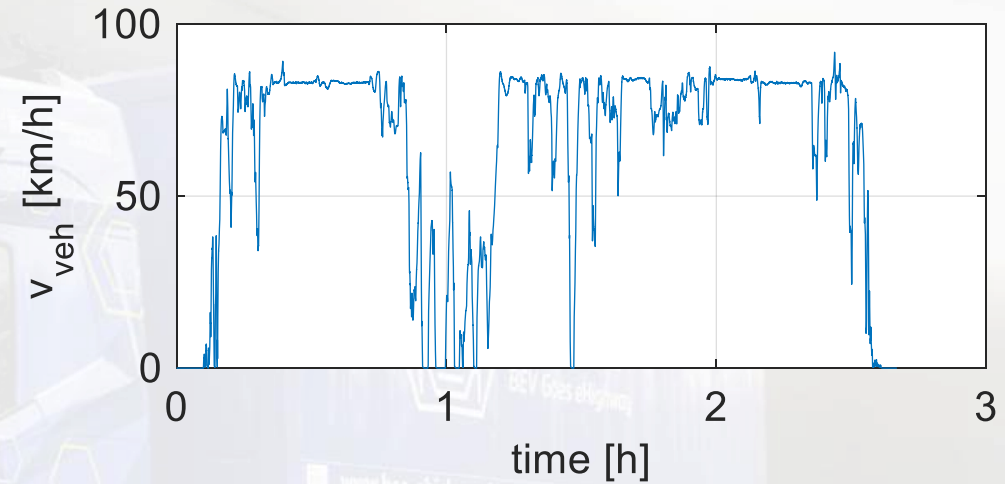
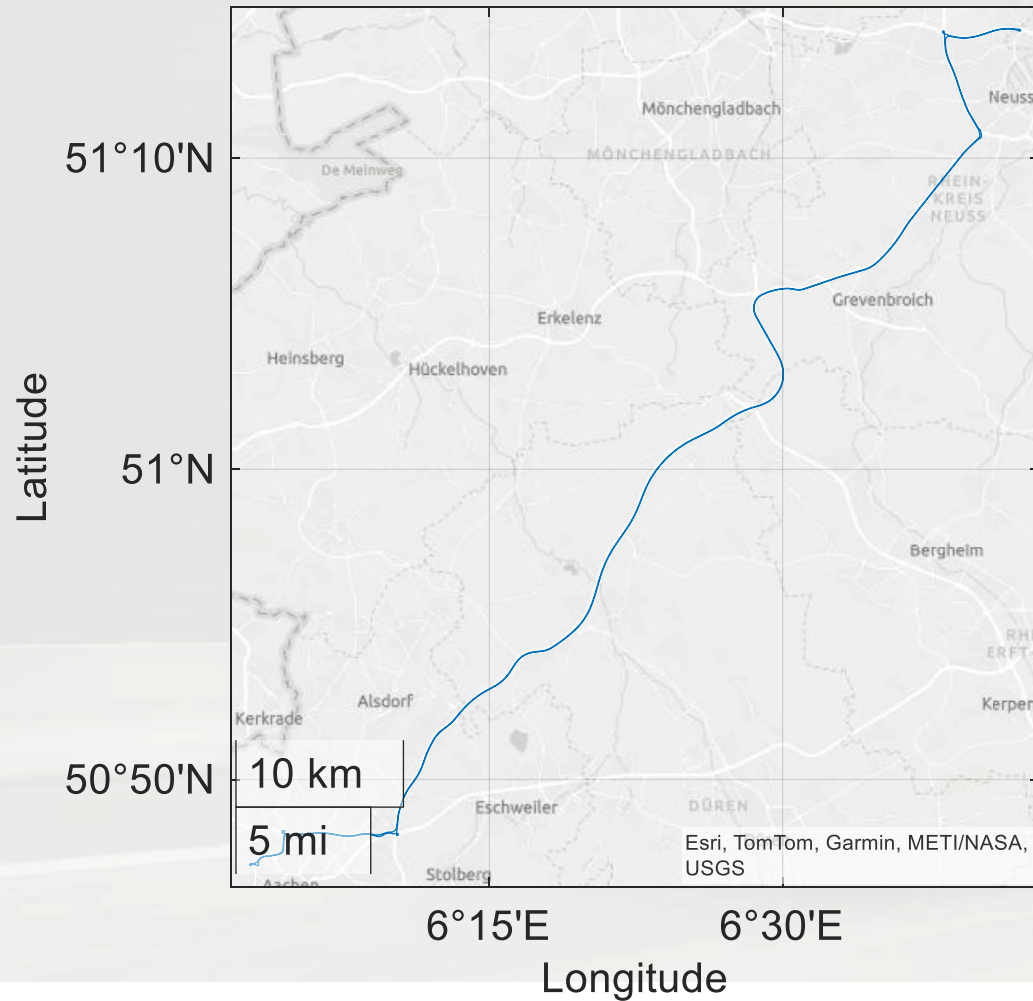
# Digital Twin

## *Input Data*



# Derivation of Driving Cycles

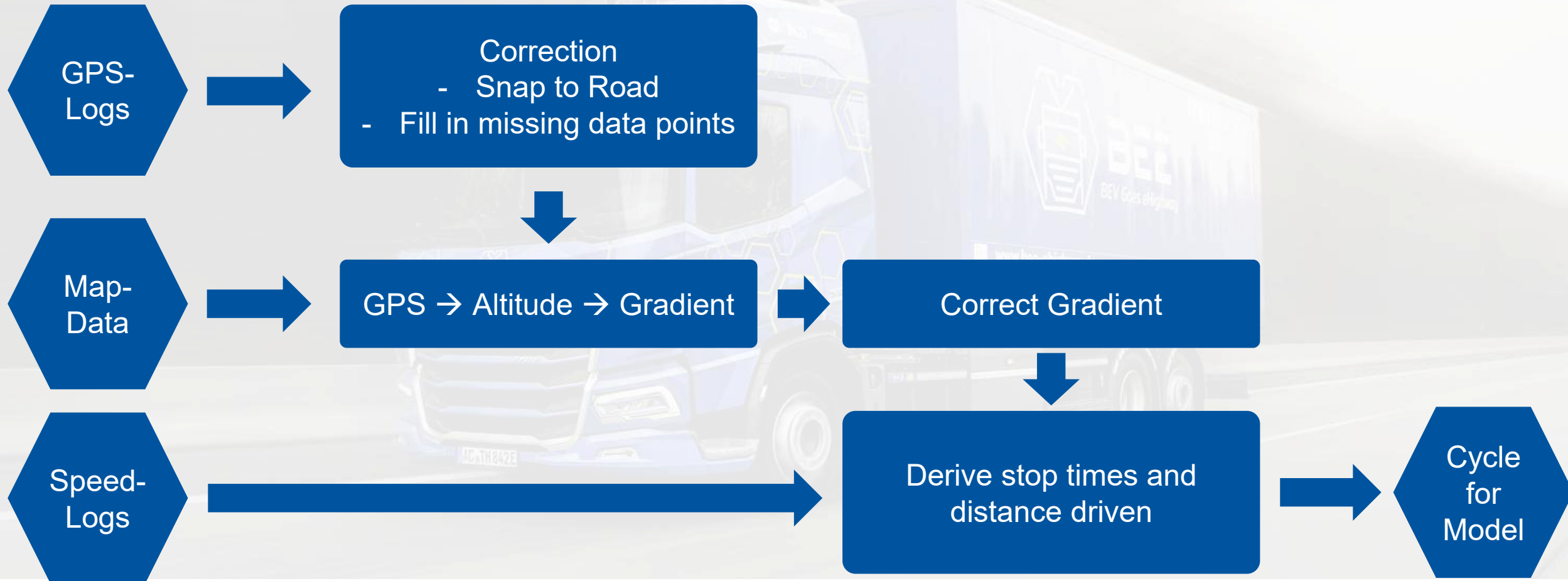
## Input Data



**Correction needed!**

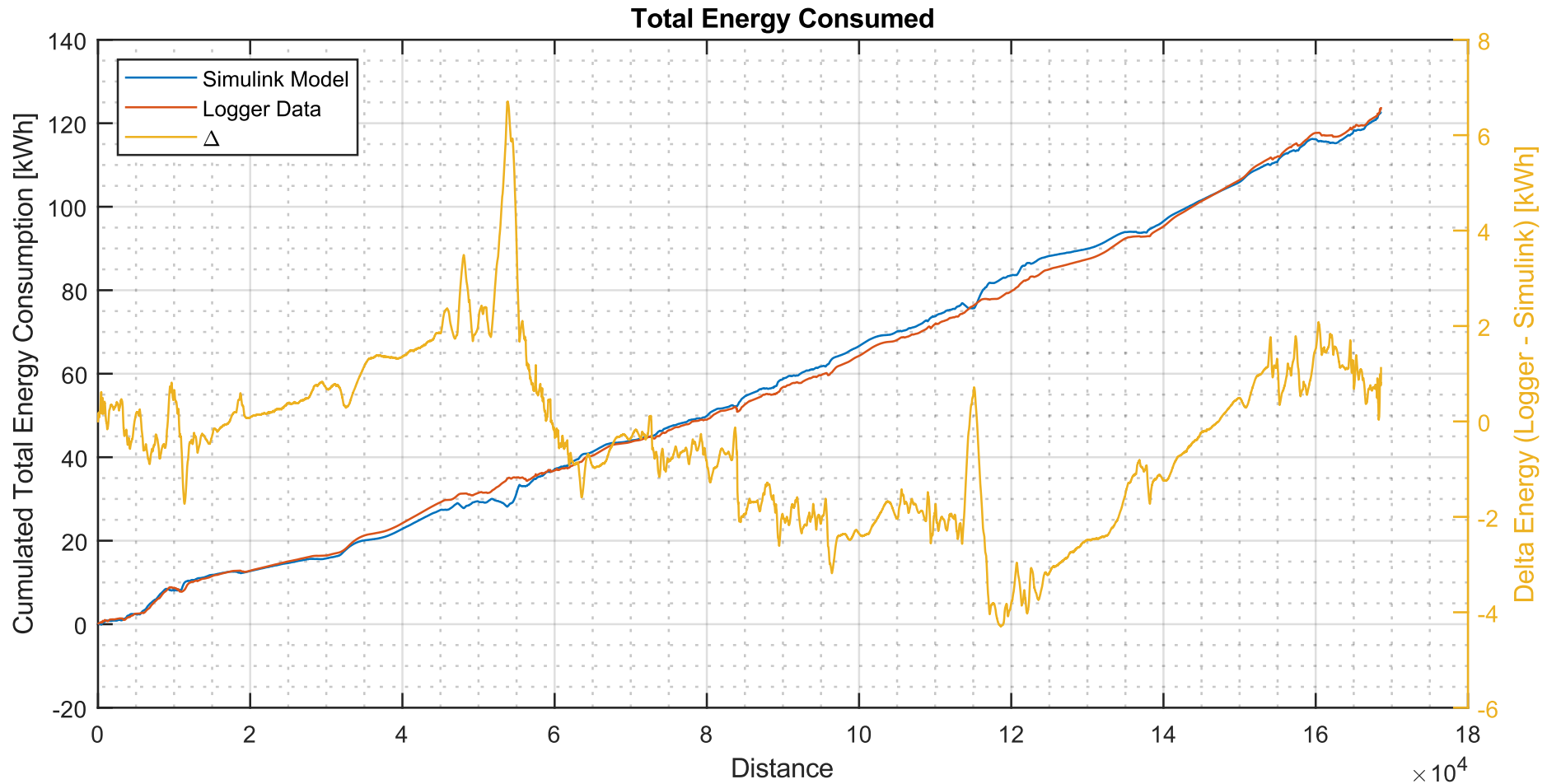
# Derivation of Driving Cycles

## Method



# Digital Twin

## Example Result - Energy Demand Prediction



# Thank you for your attention!

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**BEE**

BEV Goes eHighway



# Defining User Requirements in a Multi-Stakeholder Environment

Lotte Wagner-Douglas

*ika*

# Defining User Requirements - Approach

## Study 1: Expert Interviews

- **Method:** Open Interview (online)
- **Aim:** To collect and derive relevant research questions and topics from the perspective of stakeholders and experts in the field of BEV trucks with/ without OL-technology



## Study 2: Expert Survey

- **Method:** Survey (online)
- **Aim:** To record and weigh decision-relevant purchase criteria for BEV trucks with OL-technology



## Study 3: User Study

- **Method:** Survey-based user study in real-world traffic
- **Aim:** To assess the acceptance and usability of BEV trucks with OL-technology

# Study 1: Expert Interviews

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## Study 3: User Study

- **Method:** Survey-based user study in real-world traffic
- **Aim:** To assess the acceptance and usability of BEV trucks with OL-technology

# Study 1: Expert Interviews

## Methodology:

Semi-structured interviews based on a discussion guide with a duration of 30-60 minutes

## Procedure:

- Brief presentation of the project
- Collection of research questions or research topics:
  - *Which research questions or research topics are currently relevant to the expert?*
  - *Which users/stakeholders are affected by the research question or research topic?*
  - *Why is the research question or research topic relevant?*

# Study 1: Expert Interviews

Sample:



**N = 10**

data sets in total

## **Industry Experts ( $n = 5$ )**

Industry experts specialized in overhead line technology ( $n = 3$ ), truck manufacturing ( $n = 1$ ) or logistics ( $n = 1$ )

## **Research Experts ( $n = 5$ )**

Research experts specialized in battery technology, electric motors ( $n = 4$ ) or truck HMI ( $n = 1$ )

# Study 1: Expert Interviews

## Results:

- Analysis of the stakeholder interviews reveals two key stakeholders for the use and implementation of BEV trucks with and without OL: **truck drivers** and **logistics companies**
- With regard to **truck drivers**, the experts surveyed most frequently identified the following research topics as relevant:
  1. **HMI design:** e.g., what information should be presented in what form and how should the docking process be designed?
  2. **Driver acceptance:** e.g., what is the attitude of drivers toward the use of the technology and its perceived user-friendliness?
  3. **Driving experience:** e.g., how do vibration and noise reduction as well as acceleration behavior affect the driving experience of drivers?

# Study 1: Expert Interviews

## Results:

- Analysis of the stakeholder interviews reveals two key stakeholders for the use and implementation of BEV trucks with and without OL: **truck drivers** and **logistics companies**
- With regard to **logistics companies**, the experts surveyed most frequently identified the following research topics as relevant:
  1. **Costs of BEV trucks with/without OL:** e.g., what is the maximum purchase price/price per kilometer, is buying or leasing BEV trucks with or without OL more attractive?
  2. **Push and pull factors:** What are the advantages and disadvantages from the perspective of stakeholders?
  3. **Practicability:** e.g., what influence do battery operation and OL have on heavy transport? How are charging and break times logistically combined for BEV trucks? Are there concerns regarding the availability and distance of specialized repair shops?

# Study 2: Expert Survey

## Study 1: Expert Interviews

- **Method:** Open Interview (online)
- **Aim:** To collect and derive relevant research questions and topics from the perspective of stakeholders and experts in the field of BEV trucks with/ without OL-technology



## Study 2: Expert Survey

- **Method:** Survey (online)
- **Aim:** To record and weigh decision-relevant purchase criteria for BEV trucks with OL-technology



## Study 3: User Study

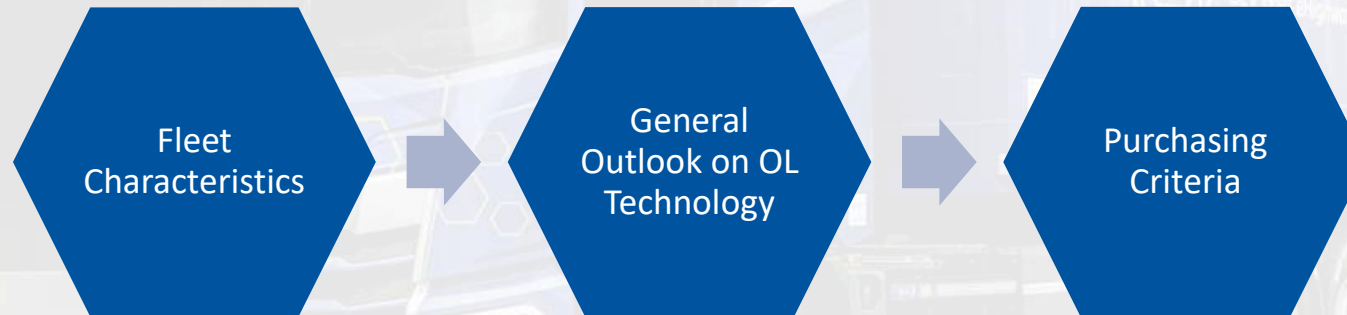
- **Method:** Survey-based user study in real-world traffic
- **Aim:** To assess the acceptance and usability of BEV trucks with OL-technology

# Study 2: Expert Survey

Methodology:

Expert online study ( $N = 12$  logistics specialists)

Procedure:

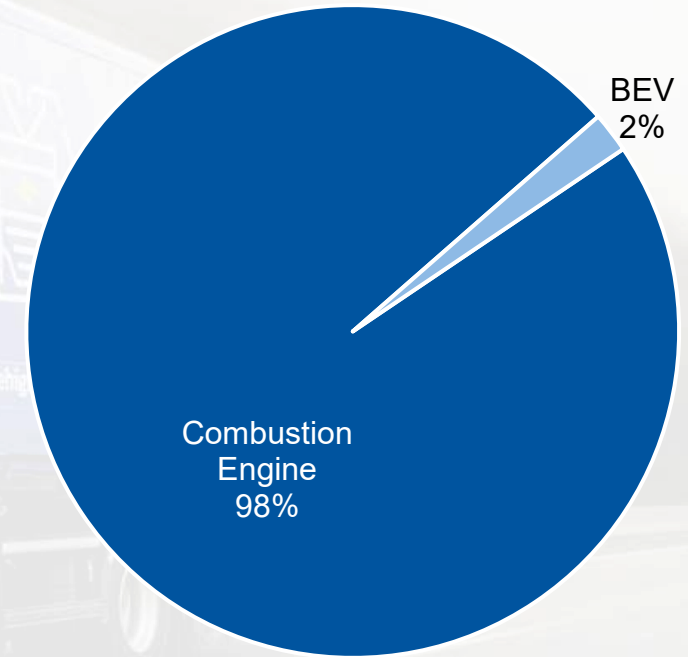
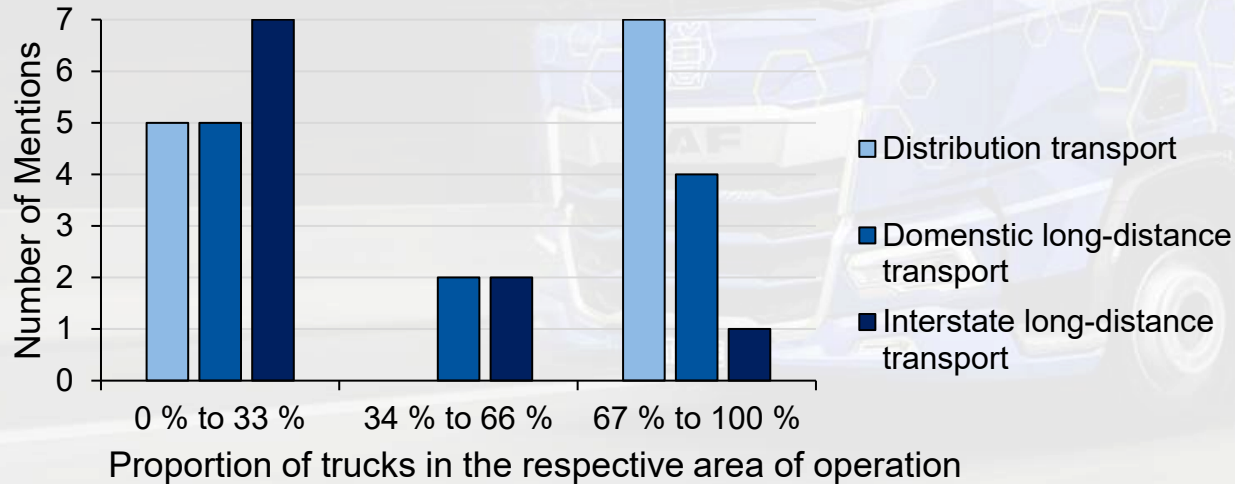


# Study 2: Expert Survey

## Results: Fleet Characteristics

- Number of trucks ( $\geq 12$  tons) in the company's fleet:

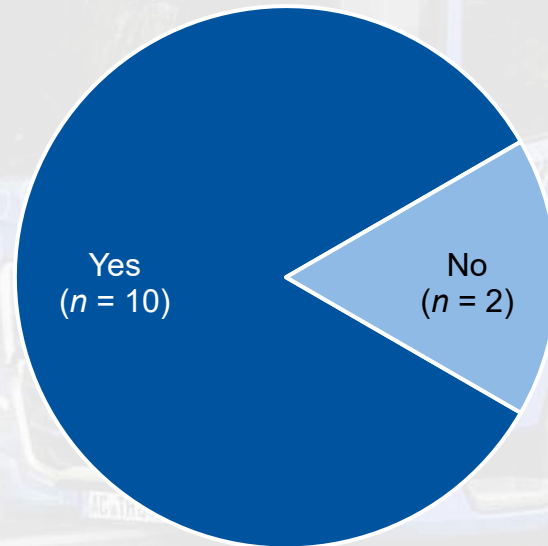
- $M = 193$
- $SD = 162.22$
- Range: 5 to 450



# Study 2: Expert Survey

## Results: General Outlook on OL Technology

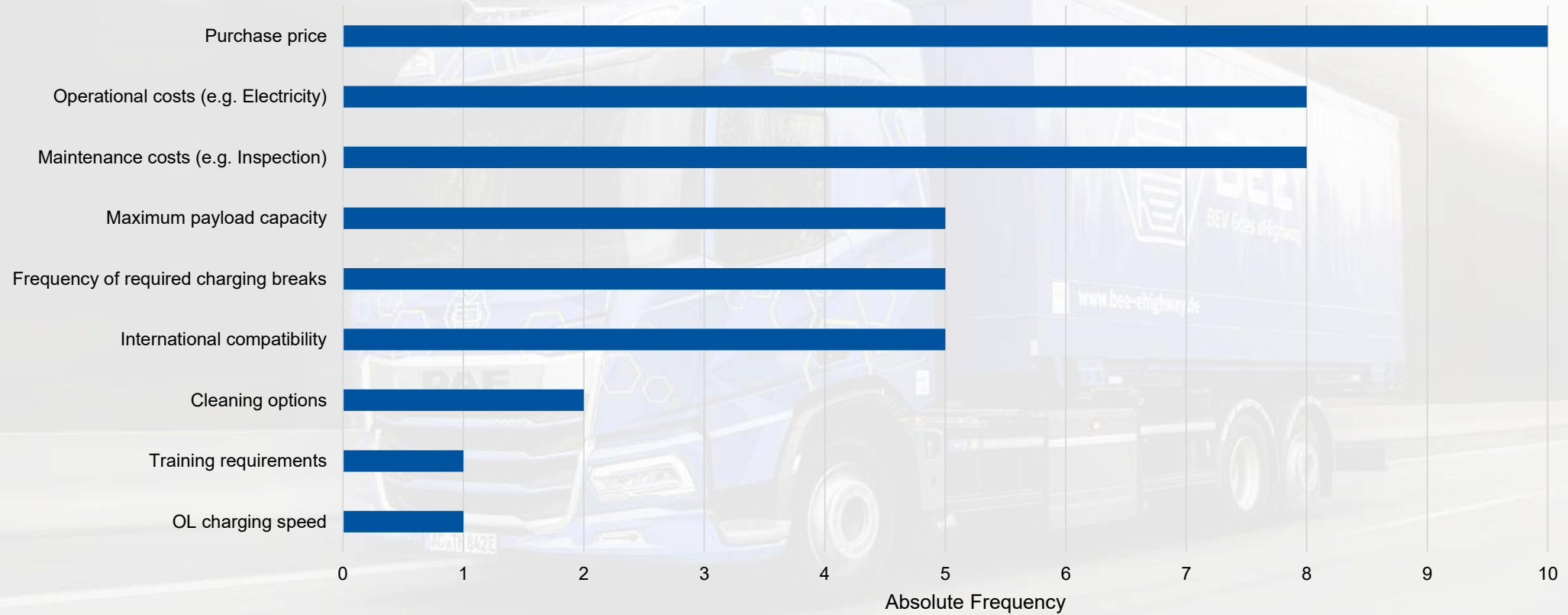
*“Assuming the infrastructure was better suited to overhead line technology: Could you see your company purchasing trucks with overhead line technology for its fleet?”*



- Doubts about international enforceability
- High costs for infrastructure
- No market for used vehicles

# Study 2: Expert Survey

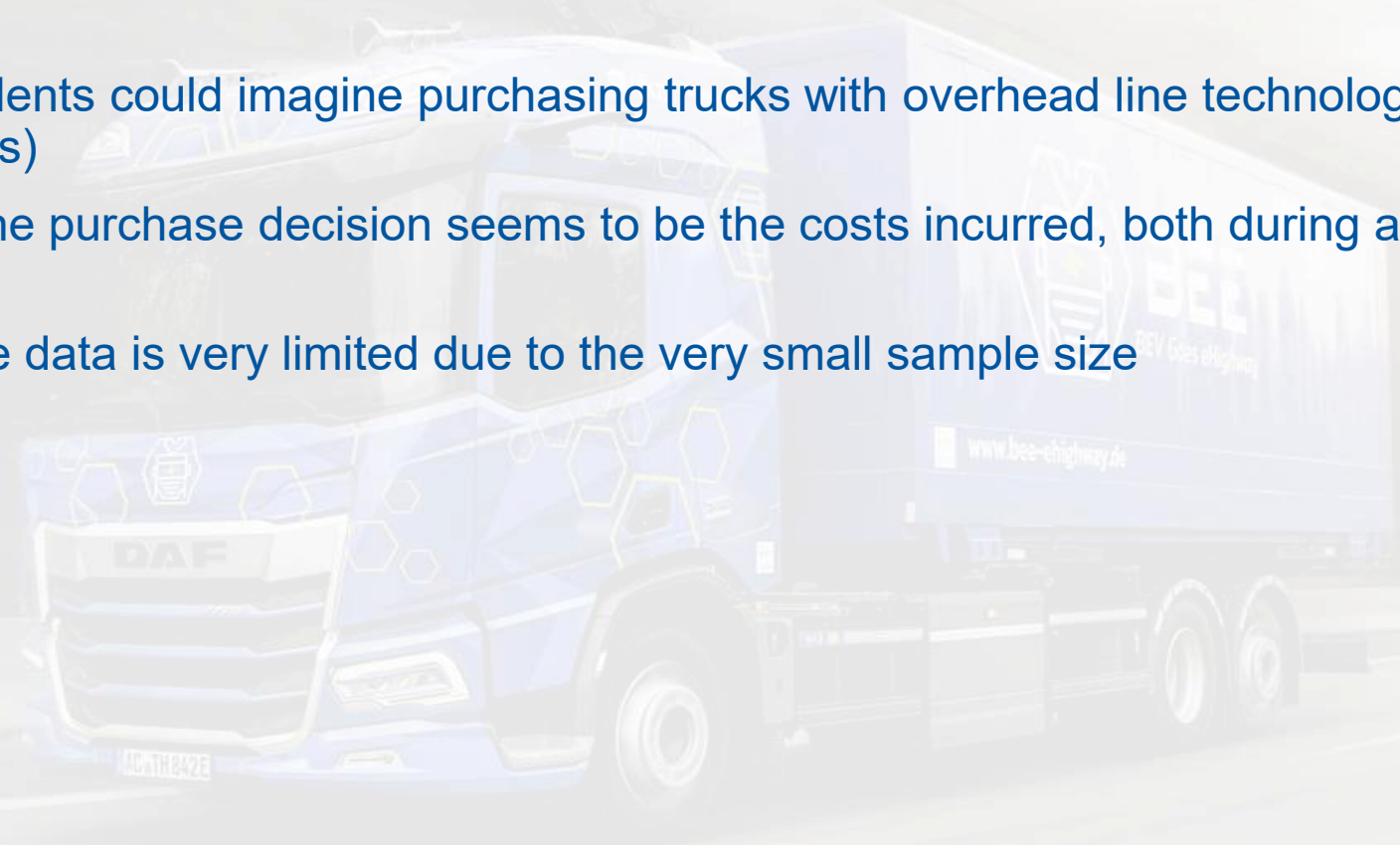
## Results: Purchase Criteria



# Study 2: Expert Survey

## Results: Summary

- The majority of respondents could imagine purchasing trucks with overhead line technology (under better infrastructural conditions)
- The decisive factor in the purchase decision seems to be the costs incurred, both during and after the purchase
- The interpretation of the data is very limited due to the very small sample size



# Study 3: User Study

## Study 1: Expert Interviews

- **Method:** Open Interview (online)
- **Aim:** To collect and derive relevant research questions and topics from the perspective of stakeholders and experts in the field of BEV trucks with/ without OL-technology



## Study 2: Expert Survey

- **Method:** Survey (online)
- **Aim:** To record and weigh decision-relevant purchase criteria for BEV trucks with OL-technology



## Study 3: User Study

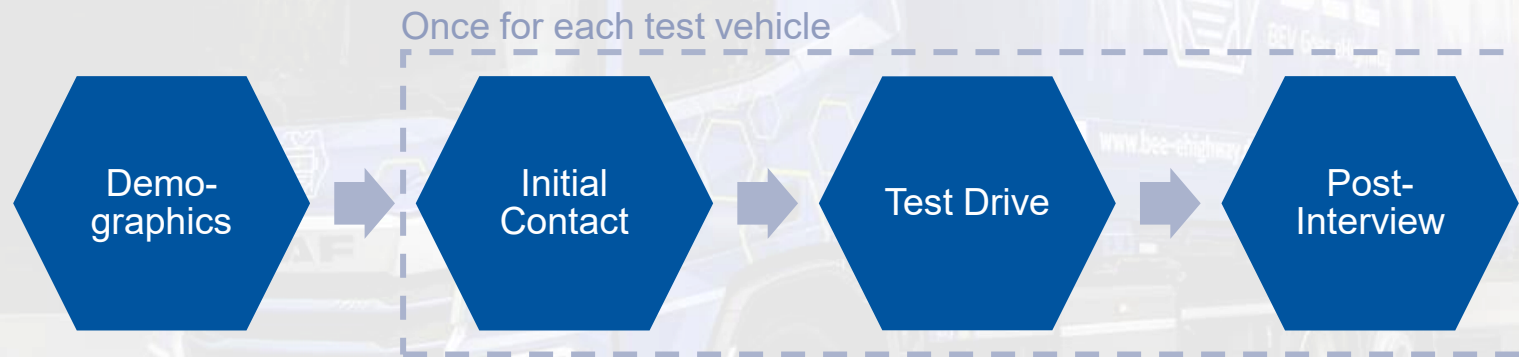
- **Method:** Survey-based user study in real-world traffic
- **Aim:** To assess the acceptance and usability of BEV trucks with OL-technology

# Study 3: User Study

Methodology:

Survey-based user study ( $N = 7$ ) in real-world traffic

Procedure:



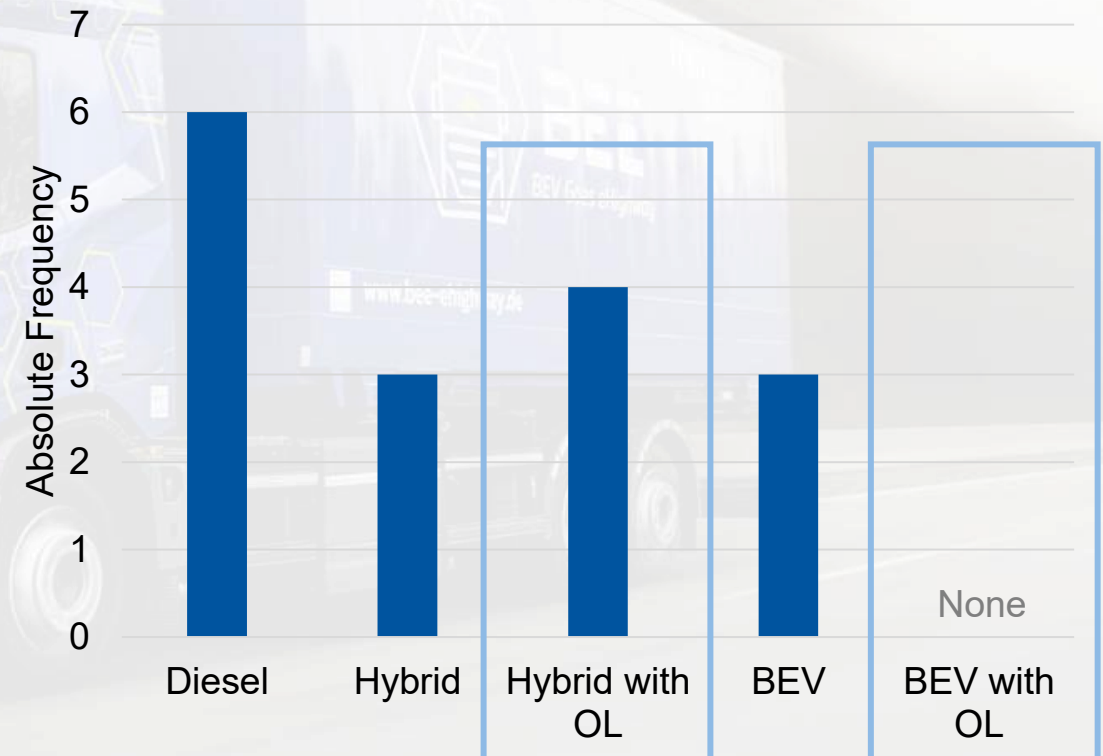
# Study 3: User Study

## Results: Demographics

### Truck driving experience:

- $M = 27.14$  years
- $SD = 11.70$  years
- $min = 5$  years
- $max = 40$  years

### Prior drive type experience:



# Study 3: User Study

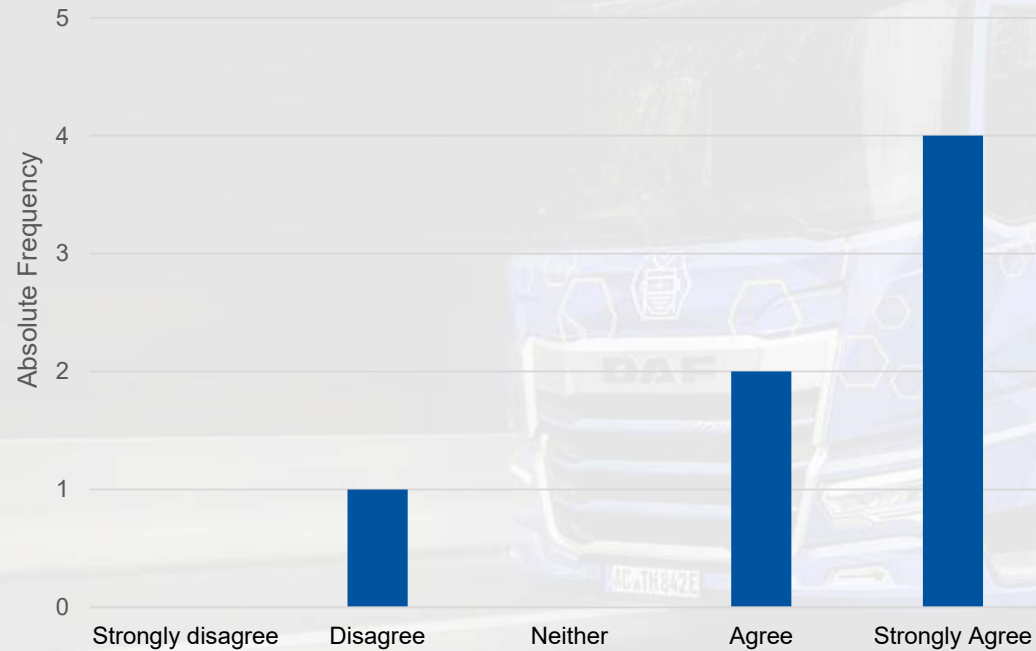
Results: Comments during the journey (regarding BEE truck)

Comments during the journey	Positive	Negative
General	<ul style="list-style-type: none"> <li>• Very quiet</li> <li>• Good acceleration</li> <li>• Cameras instead of mirrors</li> </ul>	<ul style="list-style-type: none"> <li>• No mirrors</li> <li>• No LKA</li> </ul>
Specific to Pantograph		<ul style="list-style-type: none"> <li>• Very sensitive (in terms of track)</li> <li>• Location of buttons (suggestion: steering wheel)</li> <li>• Condition of pantograph not (easily) visible + long delay</li> <li>• Operating the buttons requires practice</li> <li>• No display of charge status</li> </ul>

# Study 3: User Study

Results: Perceived environmental benefits and adoption preferences

“Overhead line trucks will make an important contribution to achieving climate protection goals in the future.”

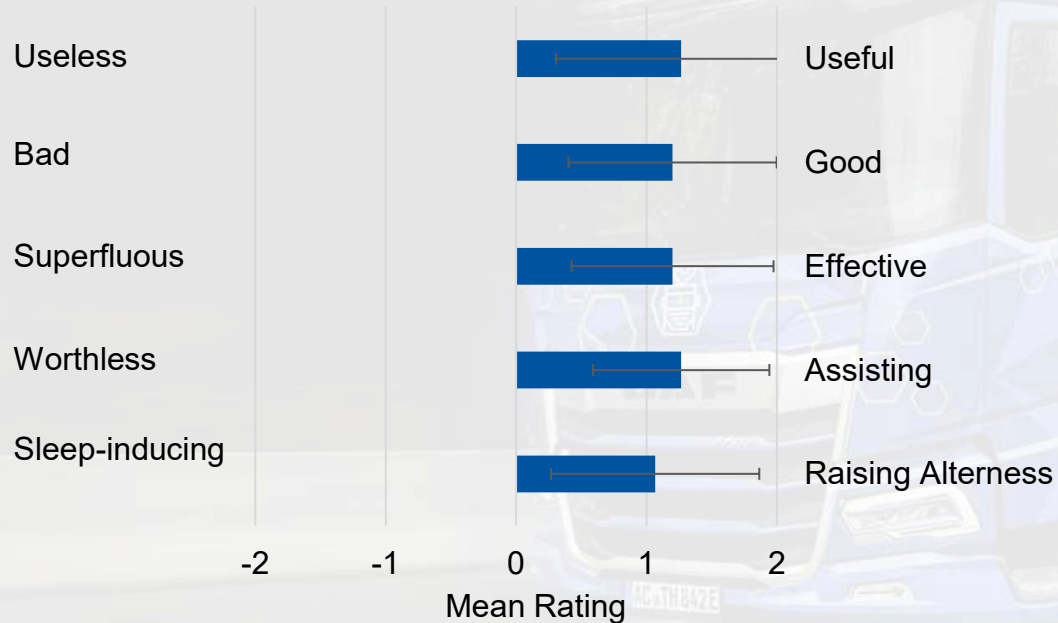


- Strong interest in automating the pantographs' connection processes
- Highlighting of quiet operation of BEVs

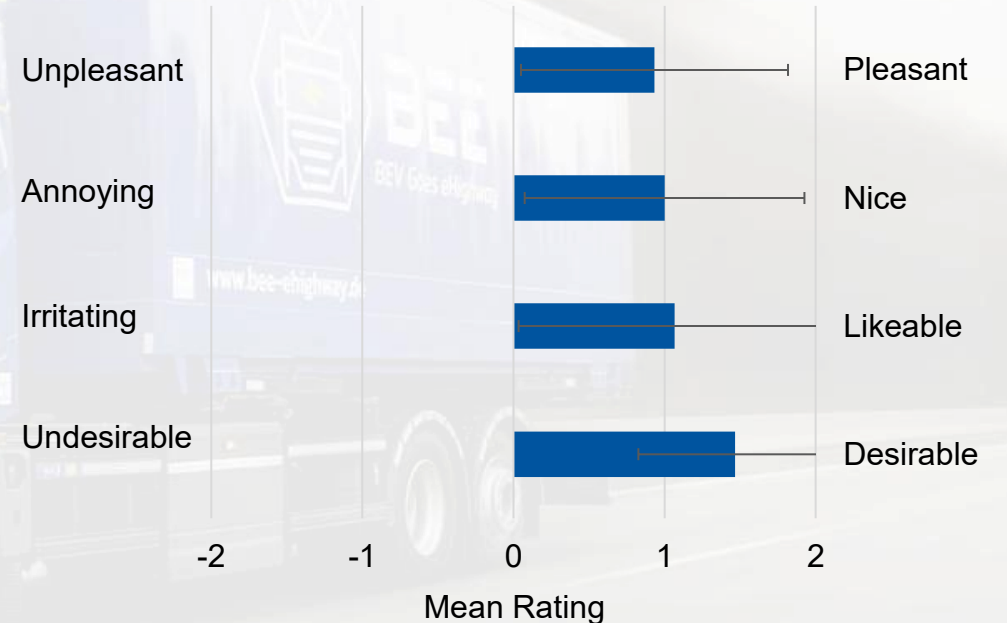
# Study 3: User Study

## Results: Usability Assessment

Usefulness Rating  
( $M = 1.20, SD = 0.78$ )



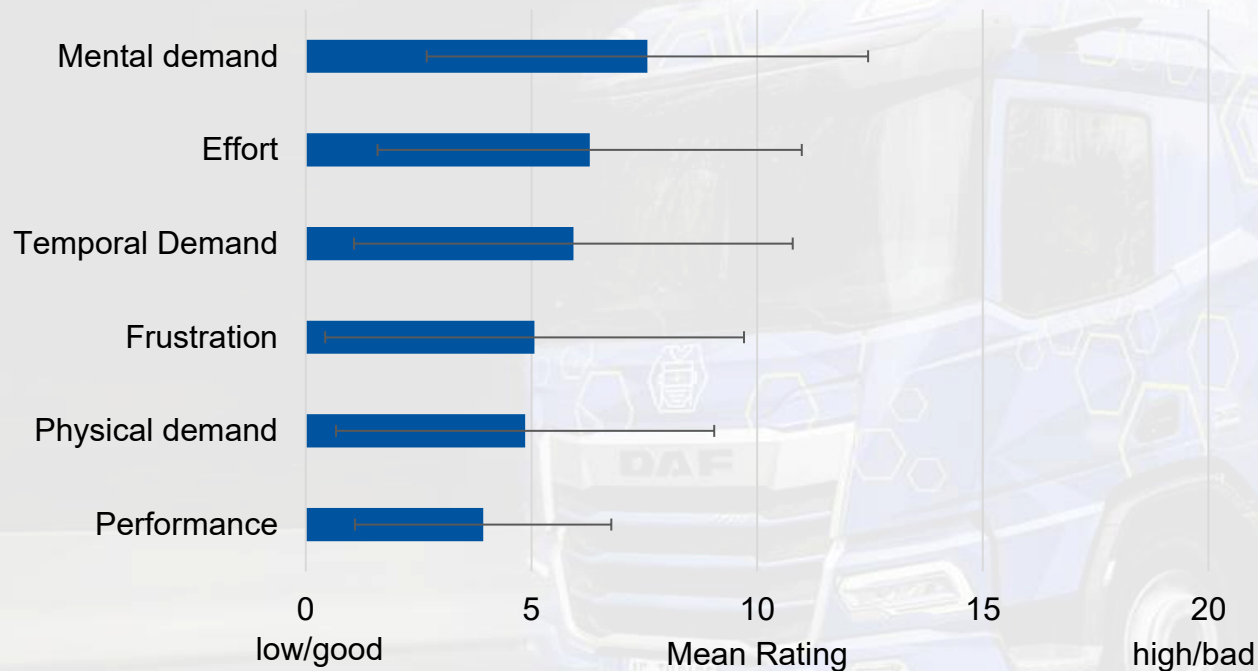
Satisfaction Rating  
( $M = 1.10, SD = 0.88$ )



➔ Overall the interaction with the pantograph control system was perceived as positive

# Study 3: User Study

## Results: Safety and Demands



- Participants indicated that they felt safe both with and without using the pantograph
- Error messages in the cockpit caused moderate unease
- Sparking from the pantograph was described as mildly concerning

# Study 3: User Study

Results: Eyetracker-Data (only BEE truck)

	Number of Fixations		Total Duration of Fixation	
	With OL	Without OL	With OL	Without OL
Traffic observation (windshield, side windows, mirrors)	71.97%	84.78%	75.77%	84.62%
Pant. Operation	16.40%	1.83%	14.50%	1.94%
Roof Window	0.17%	0.03%	0.05%	0.02%
Other	11.46%	12.94%	9.68%	11.01%

- The roof window was hardly used at all for pantograph observation
- Traffic observation decreases descriptively during sections of the route with OL, while the pantograph controls were fixed more frequently
- No difference can be seen between other areas (steering wheel/interior)

# Defining User Requirements - Conclusion

## Study 1: Expert Interviews



## Study 2: Expert Survey



## Study 3: User Study

- The conducted studies demonstrated that OL-technology for BEV and/or hybrid trucks is both technically feasible and generally well-received by relevant stakeholders
- Decision-makers acknowledge the potential of OL-technology for emission reduction and cost savings; however, they express concerns regarding infrastructure development and long-term investment security
- End users perceive the system easy to operate but identify challenges related to cognitive workload and lane-keeping precision, highlighting the need for further automation and improved feedback mechanisms
- Necessary for successful implementation:
  - Technological refinements
  - Infrastructure expansion
  - User-centered design improvements

# Thank you for your attention!

**ika** | **RWTHAACHEN**  
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**BEE**  
BEV Goes eHighway



# Optimized Route Planning

Theo Koch  
RWTH Aachen

# Work Package Overview

## Task 4.1

### Identification of Current Route Planning Processes

- Contact and survey logistics companies on route planning
- Identification and analysis of current route planning processes
- Identification of points of reference for OBEV in the process

## Task 4.2

### Integration of OBEV into Fleet Operation Planning

- Development of an approach for integrating OBEV into route planning processes
- Exemplary implementation of the approach
- Simulation and comparison of different use cases

# Task 4.1

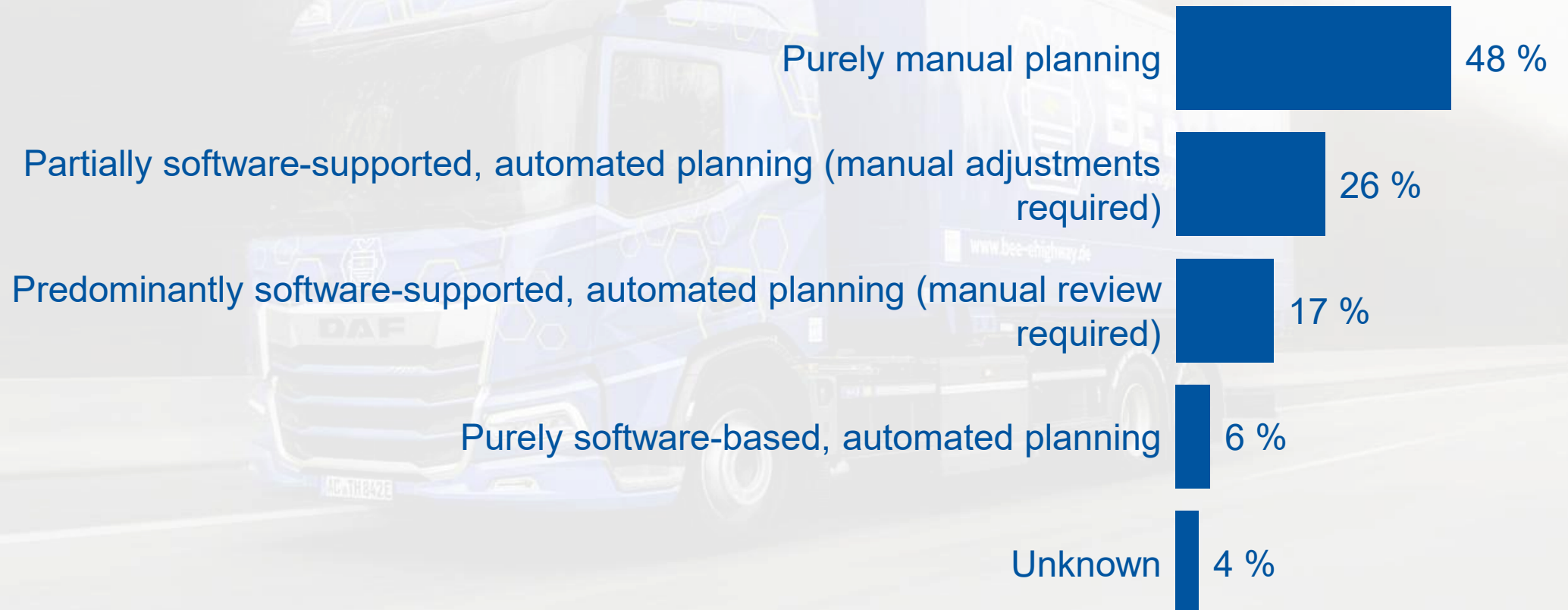
## Questionnaire



# Task 4.1

## Questionnaire

How is route planning carried out and, consequently, how are orders assigned to vehicles?

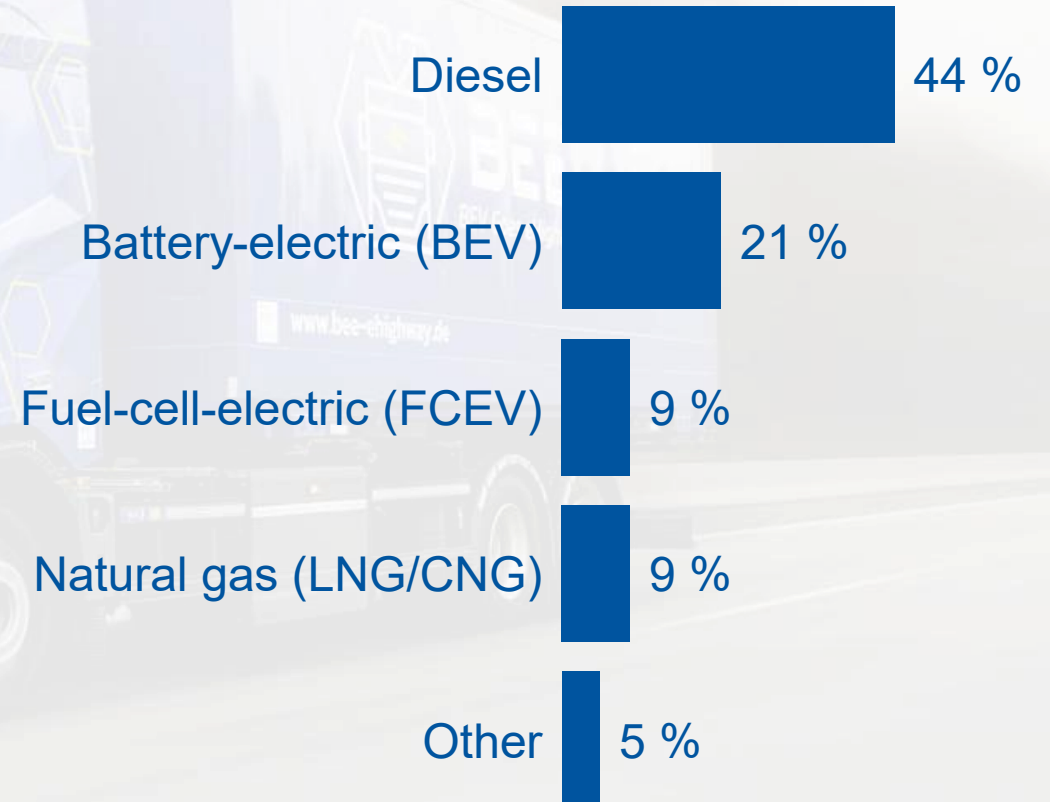


N = 82

# Task 4.1

## Questionnaire

Which powertrain technologies are supported by the software?

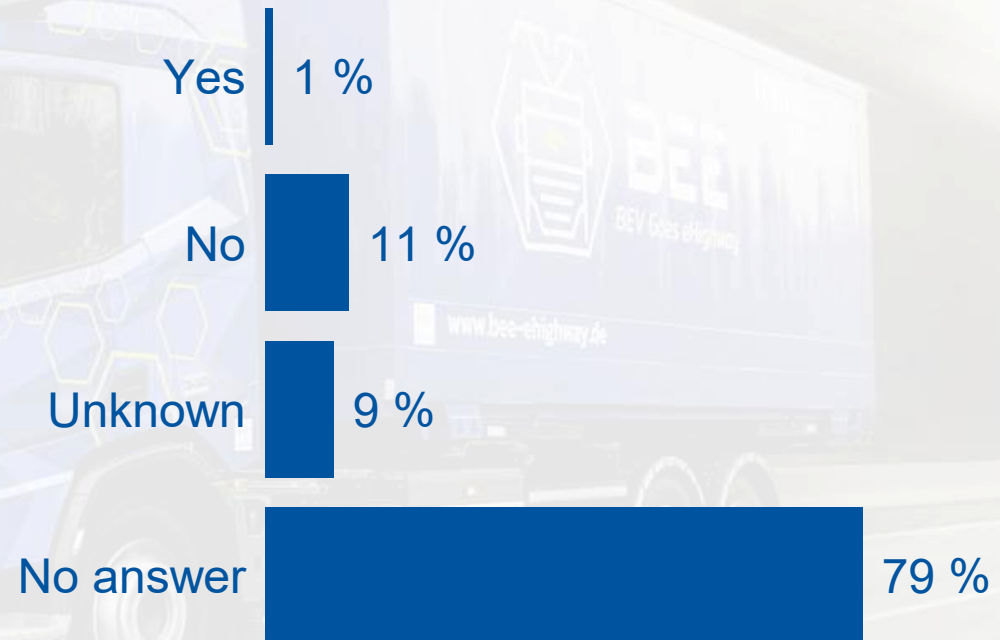


N = 82

# Task 4.1

## Questionnaire

Are battery charging processes taken into account when planning routes in the software (additional charging stops and scheduling of charging time)?

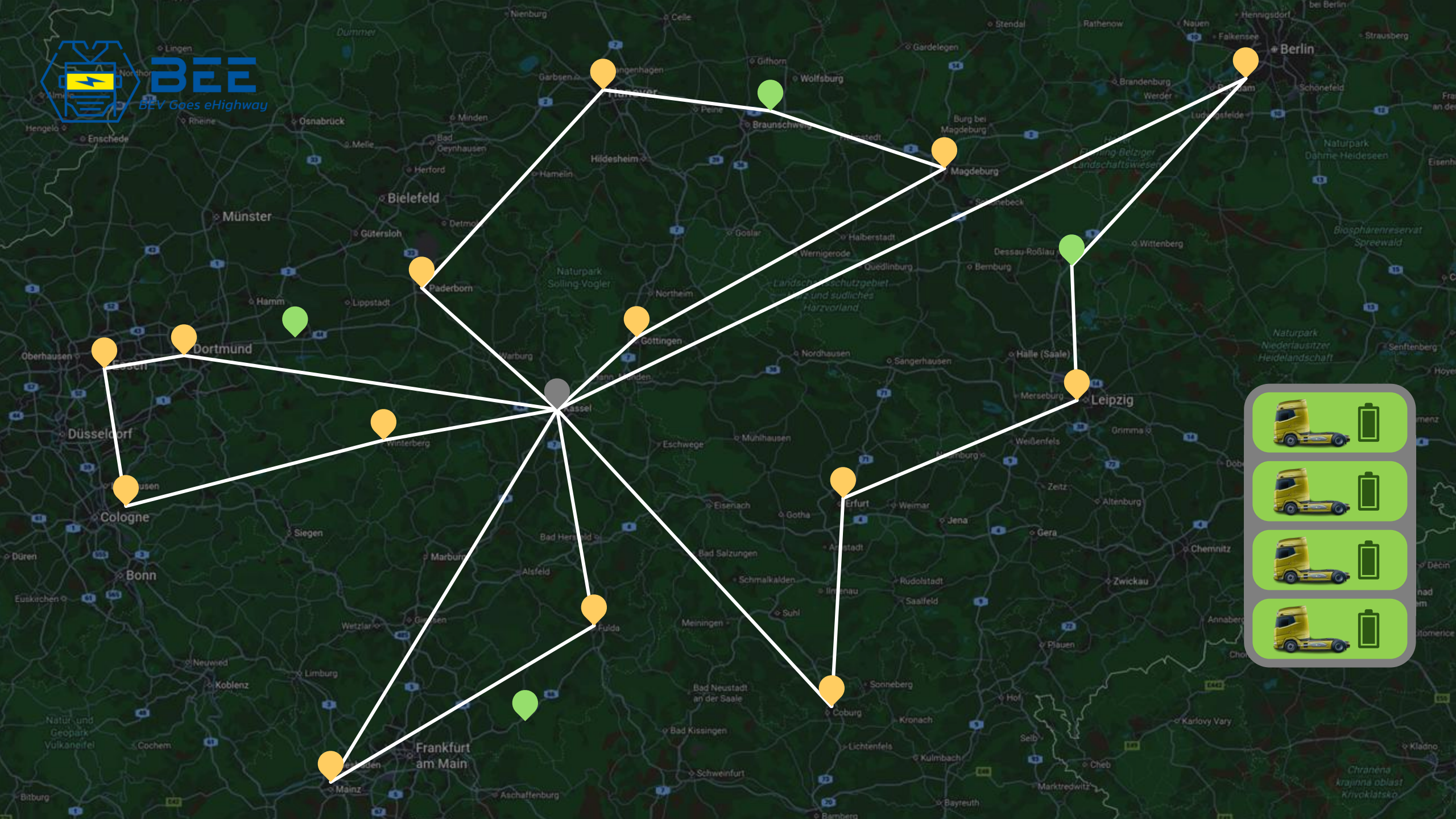


# Task 4.1

## Questionnaire

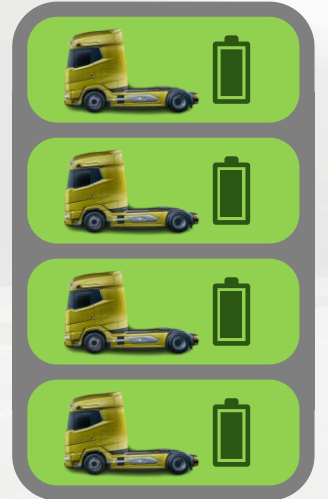
### Key Outcomes

- **Build a software model for automated and optimized route planning**
- **Integrate features for powertrain technology OBEV**



A legend box containing four rows. Each row shows a yellow truck icon next to a green battery icon, representing the vehicle type and its energy status.

**E** lectric  
**V** ehicle  
**R** outing  
**P** roblem



**E**lectric  
**V**ehicle  
**R**outing  
**P**roblem







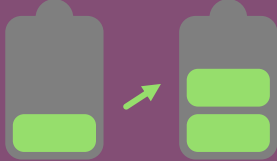
+

**Objective Function**

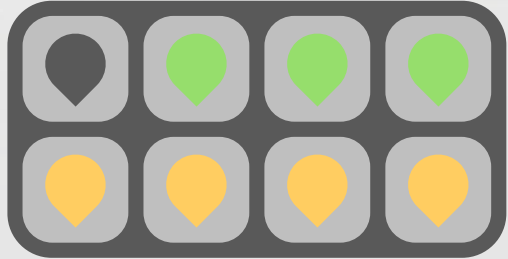
- min(*distance*)
- min(*energy*)
- min(*cost*)

+

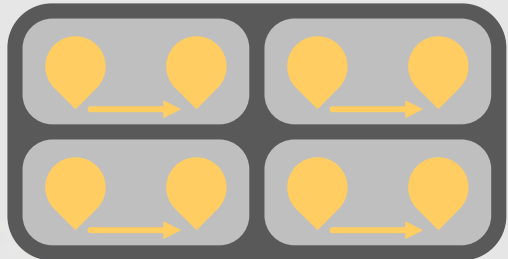
**Extensions**

- Capacitated**  

- Time Windows**  

- Mixed Fleet**  
  

- Pickup and Delivery**  

- Multi-Period**  

- Partial Charging**  


### Locations



### Orders



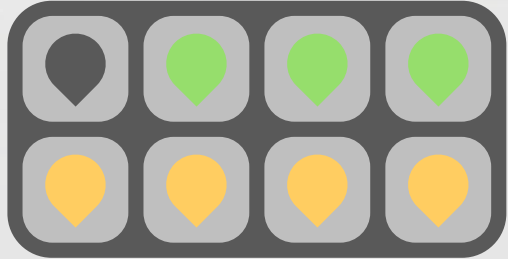
### Vehicles



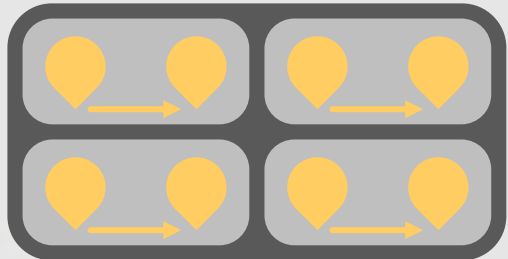
## Implementation Framework



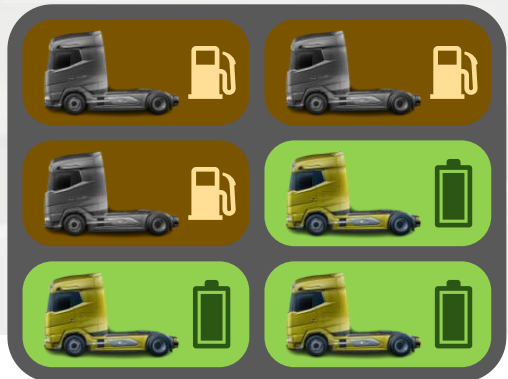
### Locations



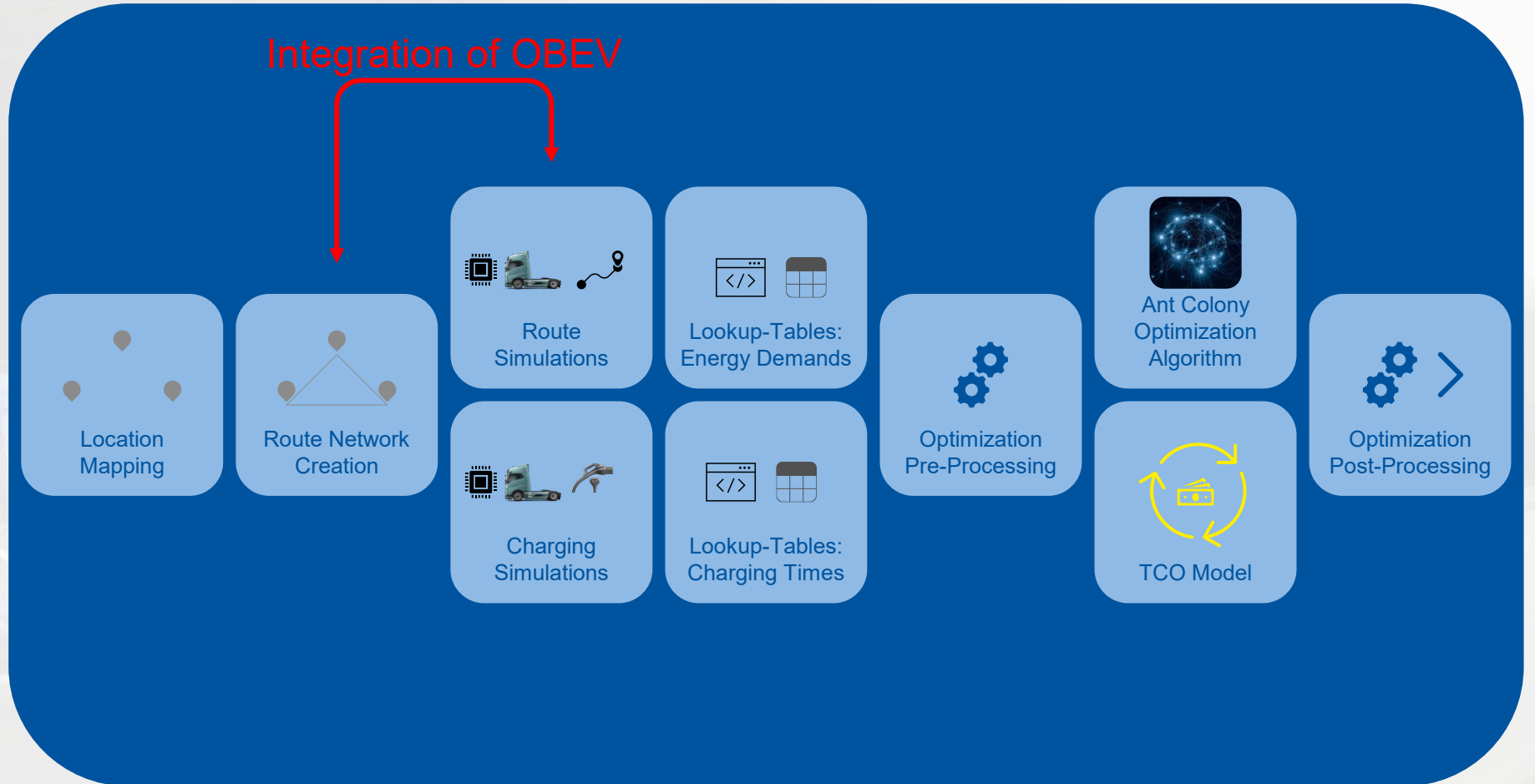
### Orders



### Vehicles



## Implementation Framework







Home



Food



Home

Food





Home

Food



$$p_1 = \frac{\tau_1}{\sum \tau_i}$$



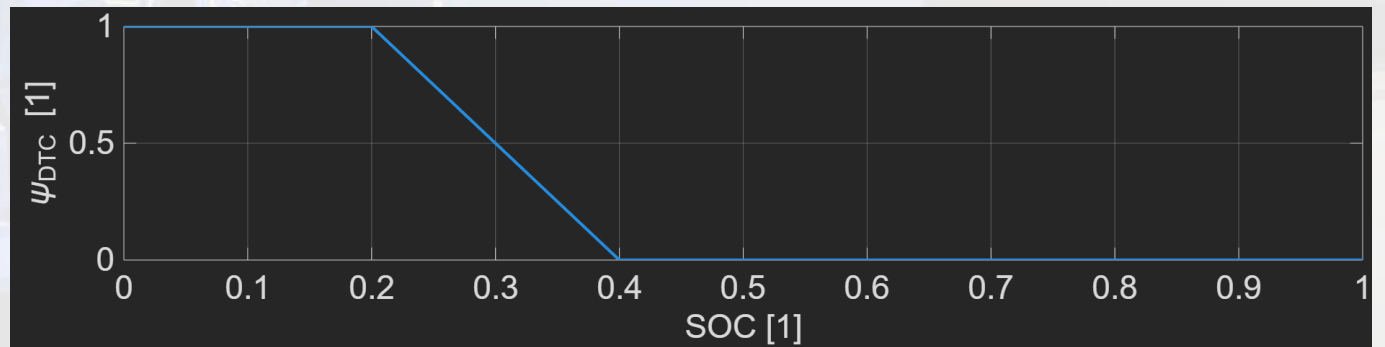
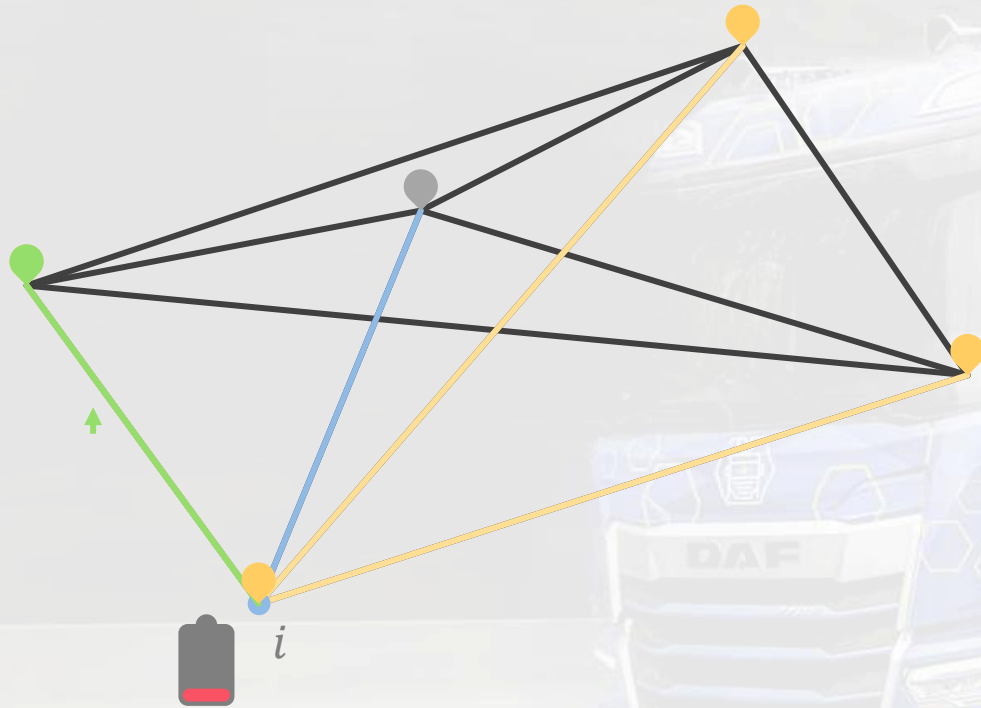


### Probability

$$p_{i,j,v} = \frac{(\tau_{i,j,v} \cdot \psi_{i,j,v})^\alpha \cdot \eta_{i,j,v}^\beta}{\sum_{j \in N, i \neq j} (\tau_{i,j,v} \cdot \psi_{i,j,v})^\alpha \cdot \eta_{i,j,v}^\beta}$$

heuristic function  $\tau_{i,j,v}$       inverse distance  $\eta_{i,j,v}$

$$\psi_{i,j,v} = 1 + C_{DTC} \cdot \psi_{DTC,i,j,v} + C_{TWA} \cdot \psi_{TWA,i,j,v} + C_{DTF} \cdot \psi_{DTF,i,j,v}$$



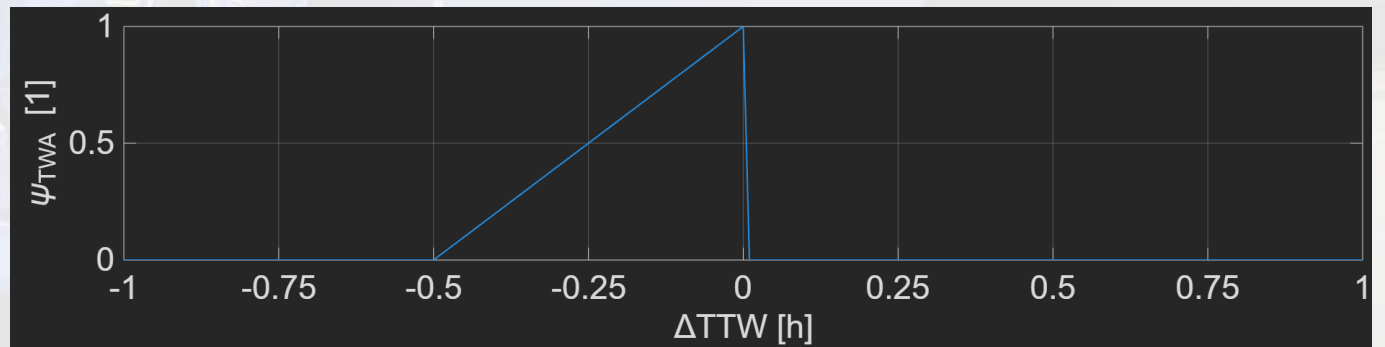
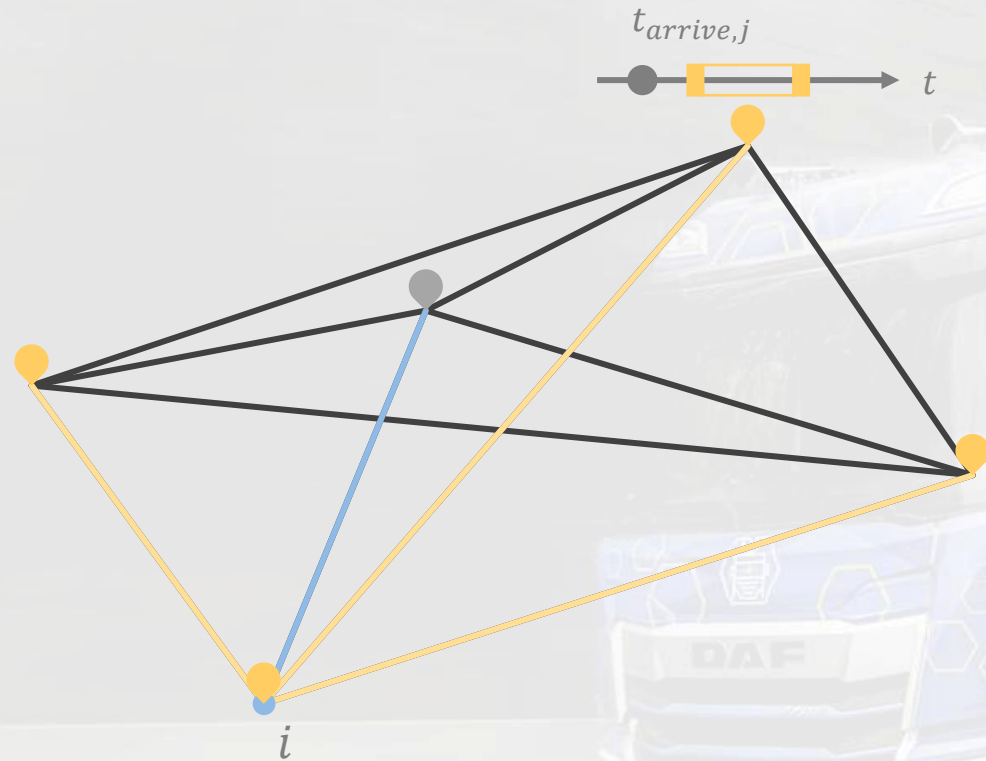
desire to charge

### Probability

$$p_{i,j,v} = \frac{(\tau_{i,j,v} \cdot \psi_{i,j,v})^\alpha \cdot \eta_{i,j,v}^\beta}{\sum_{j \in N, i \neq j} (\tau_{i,j,v} \cdot \psi_{i,j,v})^\alpha \cdot \eta_{i,j,v}^\beta}$$

heuristic function  $\psi_{i,j,v}$       inverse distance  $\eta_{i,j,v}$

$$\psi_{i,j,v} = 1 + C_{DTC} \cdot \psi_{DTC,i,j,v} + C_{TWA} \cdot \psi_{TWA,i,j,v} + C_{DTF} \cdot \psi_{DTF,i,j,v}$$



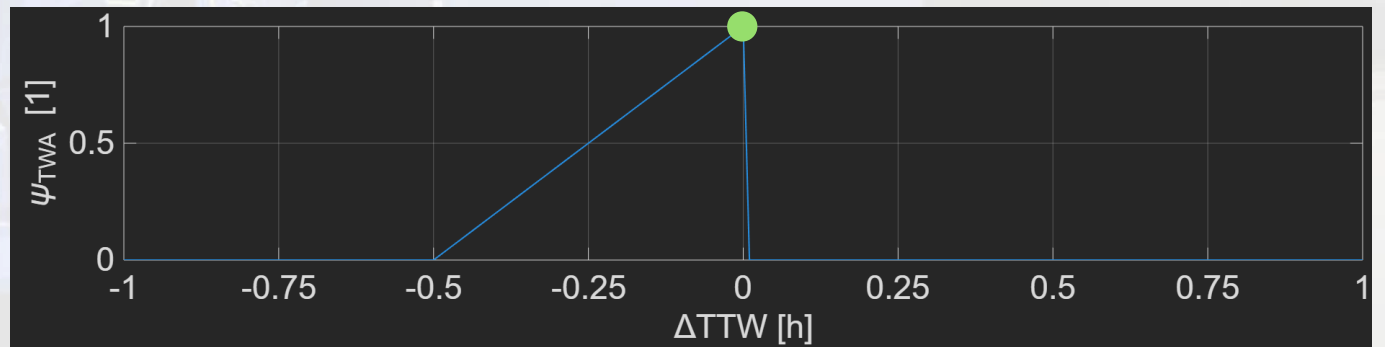
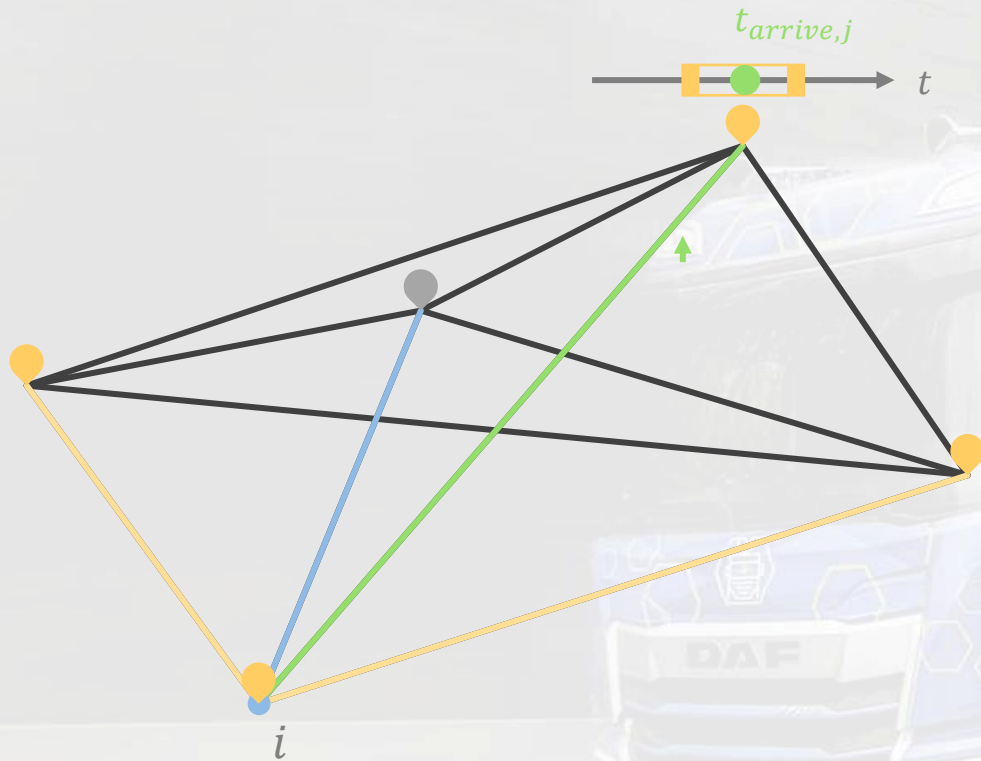
time window attraction

### Probability

$$p_{i,j,v} = \frac{(\tau_{i,j,v} \cdot \psi_{i,j,v})^\alpha \cdot \eta_{i,j,v}^\beta}{\sum_{j \in N, i \neq j} (\tau_{i,j,v} \cdot \psi_{i,j,v})^\alpha \cdot \eta_{i,j,v}^\beta}$$

heuristic function  $\psi_{i,j,v}$       inverse distance  $\eta_{i,j,v}$

$$\psi_{i,j,v} = 1 + C_{DTC} \cdot \psi_{DTC,i,j,v} + C_{TWA} \cdot \psi_{TWA,i,j,v} + C_{DTF} \cdot \psi_{DTF,i,j,v}$$



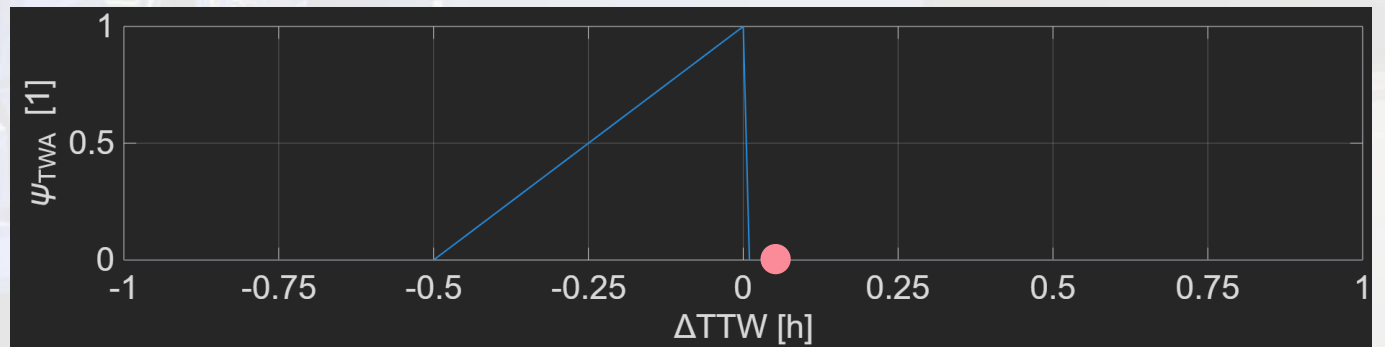
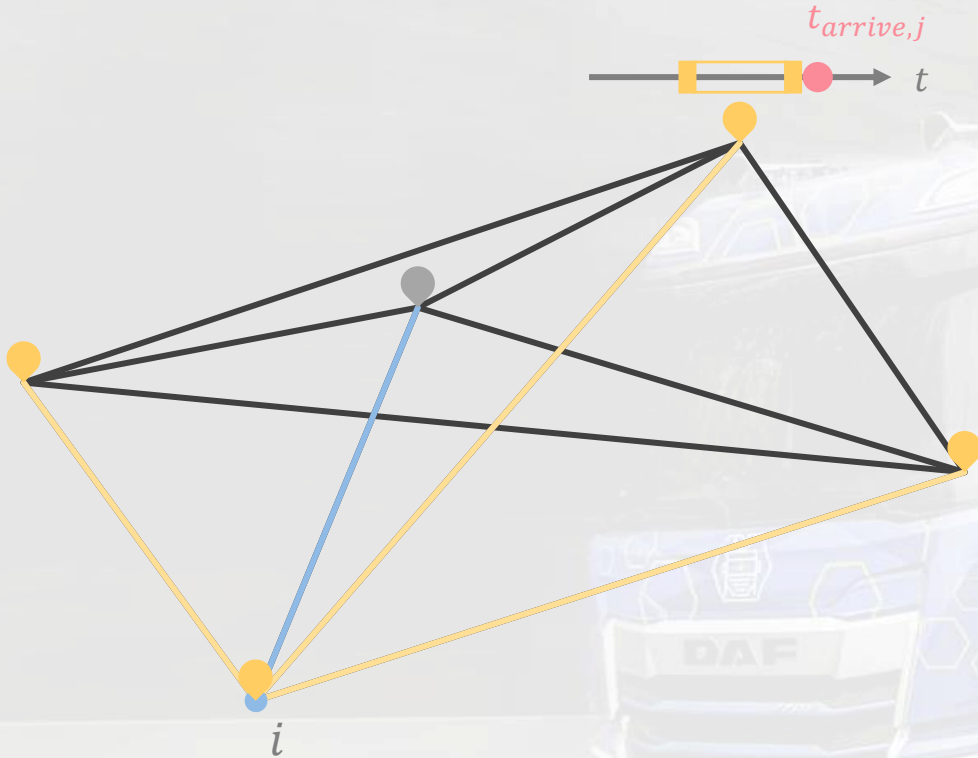
time window attraction

### Probability

$$p_{i,j,v} = \frac{(\tau_{i,j,v} \cdot \psi_{i,j,v})^\alpha \cdot \eta_{i,j,v}^\beta}{\sum_{j \in N, i \neq j} (\tau_{i,j,v} \cdot \psi_{i,j,v})^\alpha \cdot \eta_{i,j,v}^\beta}$$

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time window attraction

shift time

maximum shift time

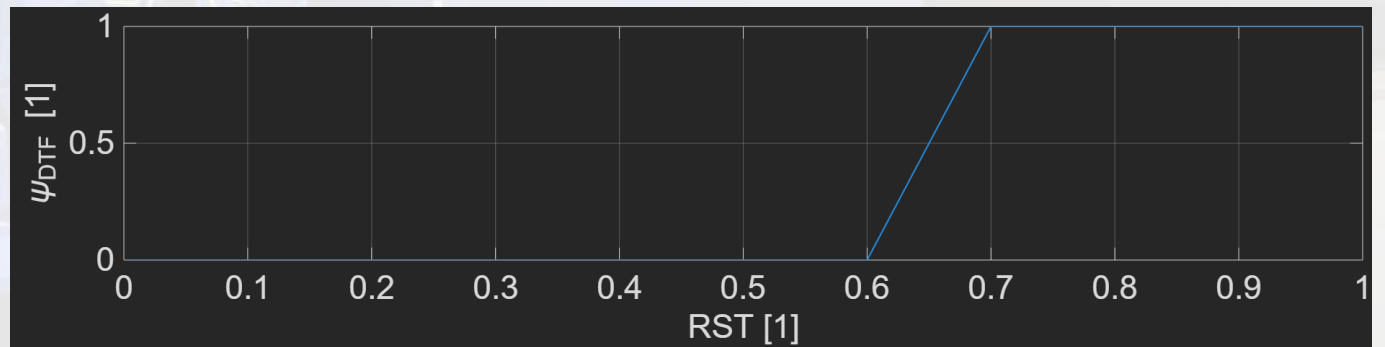


### Probability

$$p_{i,j,v} = \frac{(\tau_{i,j,v} \cdot \psi_{i,j,v})^\alpha \cdot \eta_{i,j,v}^\beta}{\sum_{j \in N, i \neq j} (\tau_{i,j,v} \cdot \psi_{i,j,v})^\alpha \cdot \eta_{i,j,v}^\beta}$$

heuristic function  $\psi_{i,j,v}$       inverse distance  $\eta_{i,j,v}$

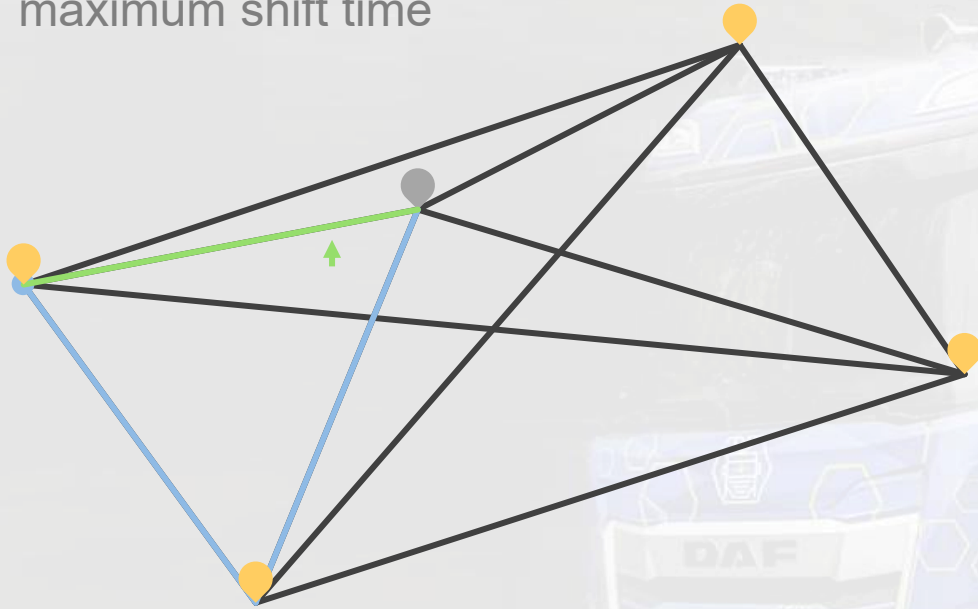
$$\psi_{i,j,v} = 1 + C_{DTC} \cdot \psi_{DTC,i,j,v} + C_{TWA} \cdot \psi_{TWA,i,j,v} + C_{DTF} \cdot \psi_{DTF,i,j,v}$$



desire to finish shift

shift time

maximum shift time

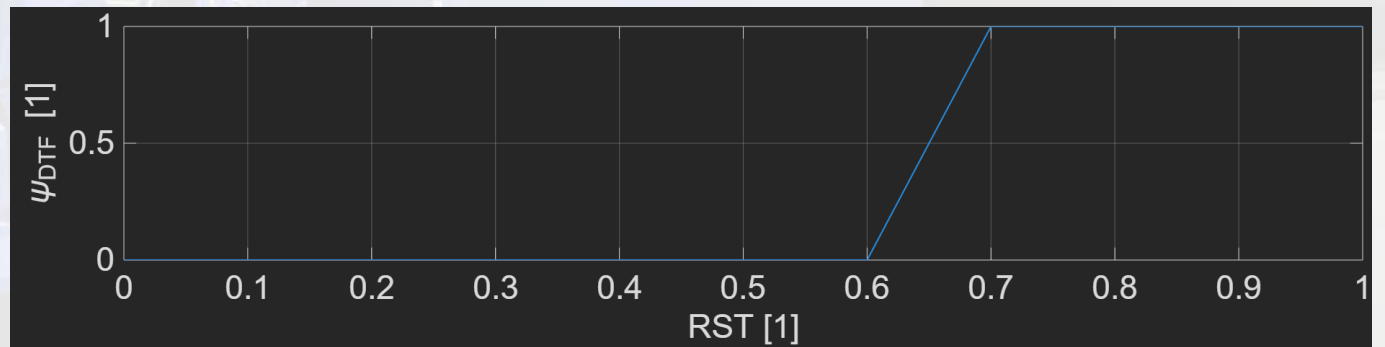


Probability

$$p_{i,j,v} = \frac{(\tau_{i,j,v} \cdot \psi_{i,j,v})^\alpha \cdot \eta_{i,j,v}^\beta}{\sum_{j \in N, i \neq j} (\tau_{i,j,v} \cdot \psi_{i,j,v})^\alpha \cdot \eta_{i,j,v}^\beta}$$

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desire to finish shift

Total Costs per Vehicle

$$TC_v = C_{CAPEX} + C_{energy} + C_{toll} + C_{CO2} + C_{labor} + C_{insurance}$$

Total Costs

$$TC = \sum TC_v$$

Objective Function Value

$$OFV = TC + C_{penalty}$$

### Iteration Leaderboard *i*

Rank	OFV	Solution Details
1	1092	_____
2	1203	_____
3	1318	_____
4	1456	_____
5	1659	_____
6	1734	_____
7	1847	_____
8	1921	_____

### Global Leaderboard *i*

Rank	OFV	Solution Details
1	1092	_____
2	1203	_____
3	1318	_____
4	1456	_____
5	1659	_____
6	1734	_____
7	1847	_____
8	1921	_____

### Iteration Leaderboard $i+1$

Rank	OFV	Solution Details
1	1145	_____
2	1267	_____
3	1398	_____
4	1524	_____
5	1681	_____
6	1793	_____
7	1856	_____
8	1972	_____

### Global Leaderboard $i$

Rank	OFV	Solution Details
1	1092	_____
2	1203	_____
3	1318	_____
4	1456	_____
5	1659	_____
6	1734	_____
7	1847	_____
8	1921	_____

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Rank	OFV	Solution Details
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2	1145	_____
3	1203	_____
4	1267	_____
5	1318	_____
6	1398	_____
7	1456	_____
8	1524	_____

## Evaporation and Distribution

### Global Leaderboard $i + 1$

Rank	OFV	Solution Details
1	1092	_____
2	1145	_____
3	1203	_____
4	1267	_____
5	1318	_____
6	1398	_____
7	1456	_____
8	1524	_____

$$\tau_{i,j} \leftarrow \tau_{i,j} \cdot (1 - \rho) + \sum_a \Delta\tau_{i,j,a}$$

Distribution Amount

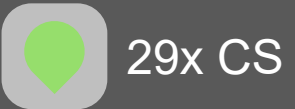
$$\Delta\tau_{i,j,a} = \frac{1}{\frac{OFV_a}{OFV_{min}} \cdot K_{\tau,max}}$$

Pheromone Value Limits

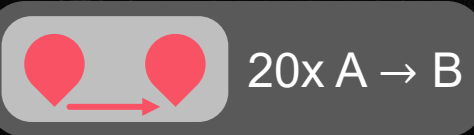
$$\tau_{max} = \frac{1}{K_{\tau,max}}$$

$$\tau_{min} = \tau_{max} \cdot \frac{K_{\tau,min}}{n_{customers}^\gamma}$$

## Locations



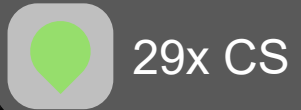
## Orders



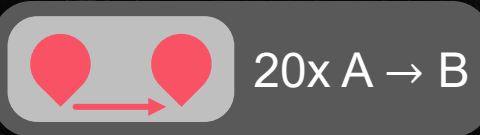
## Vehicles



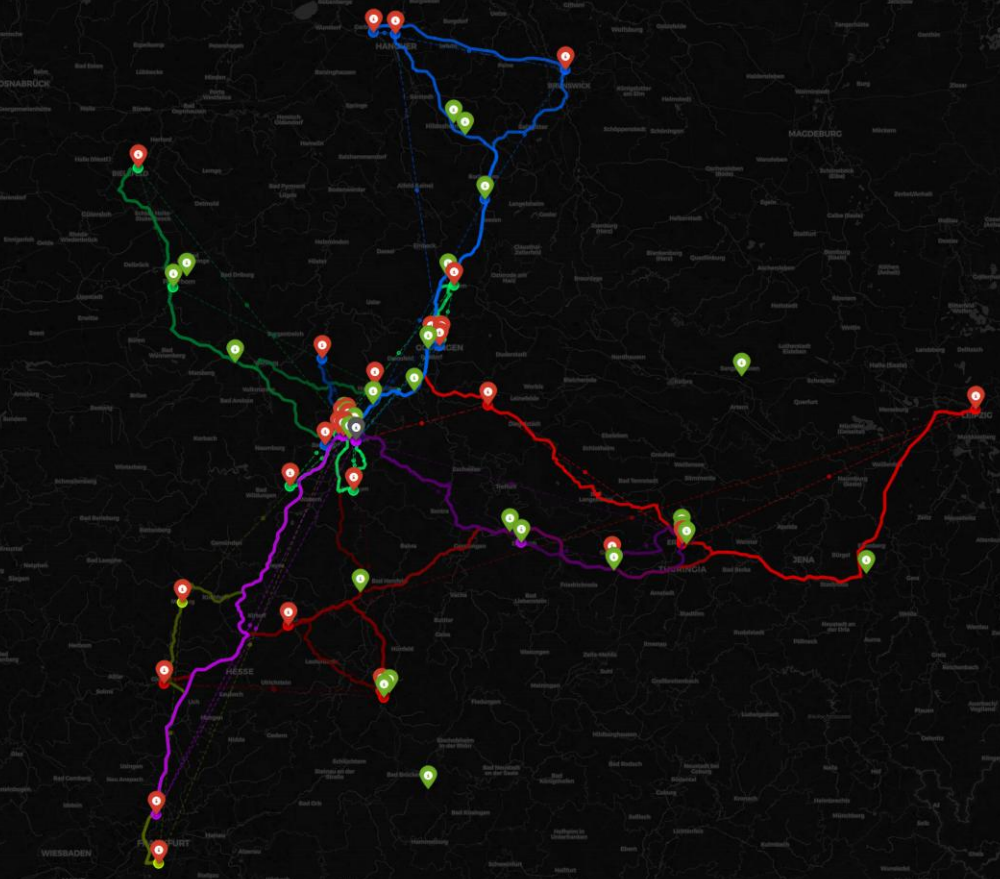
## Locations



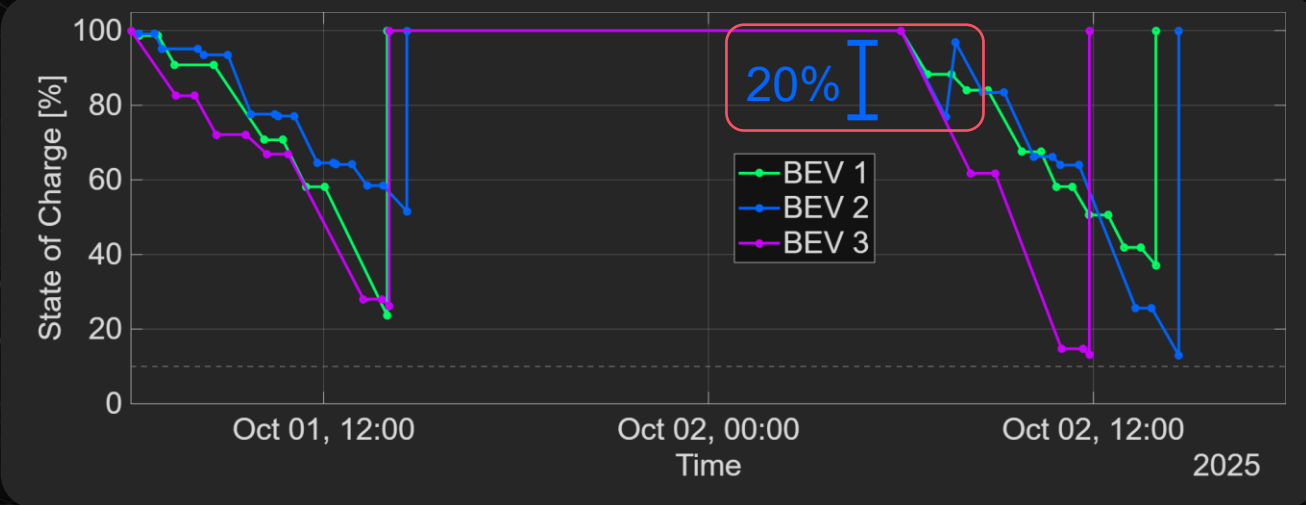
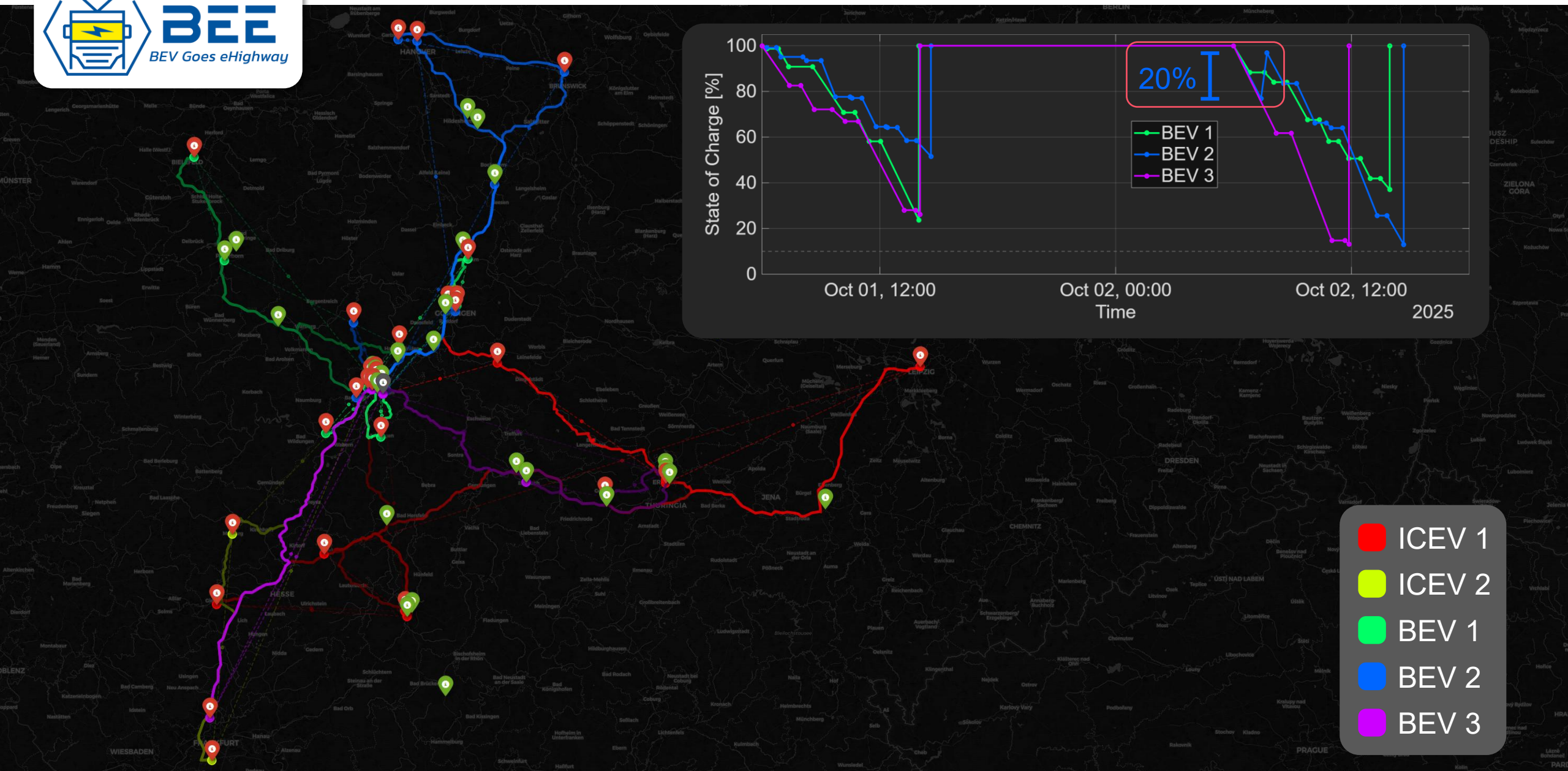
## Orders



## Vehicles





- ICEV 1
- ICEV 2
- BEV 1
- BEV 2
- BEV 3

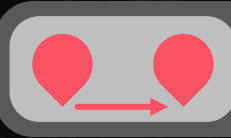


- ICEV 1
- ICEV 2
- BEV 1
- BEV 2
- BEV 3

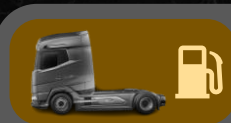

## Locations

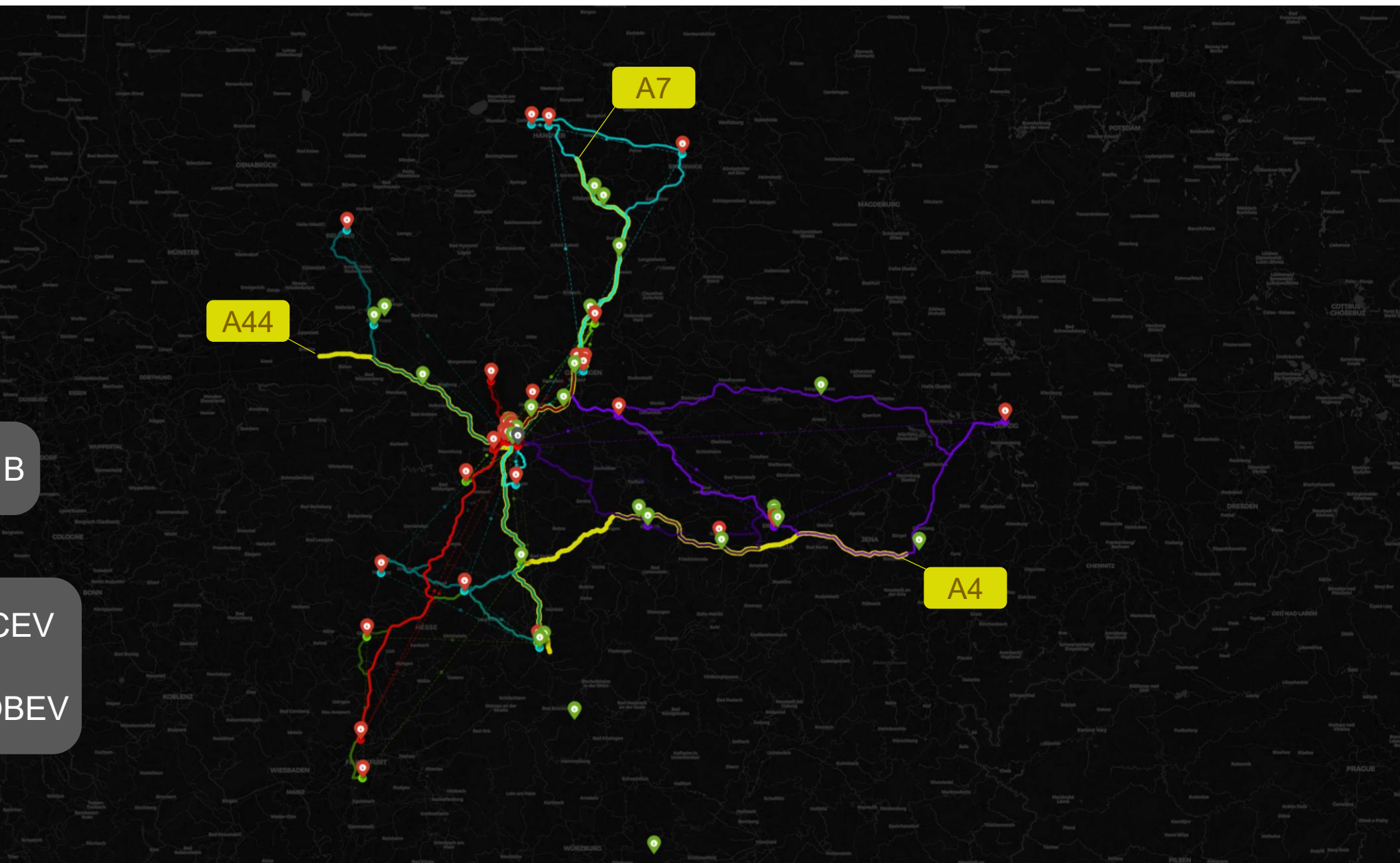
-  1x Depot
-  29x CS

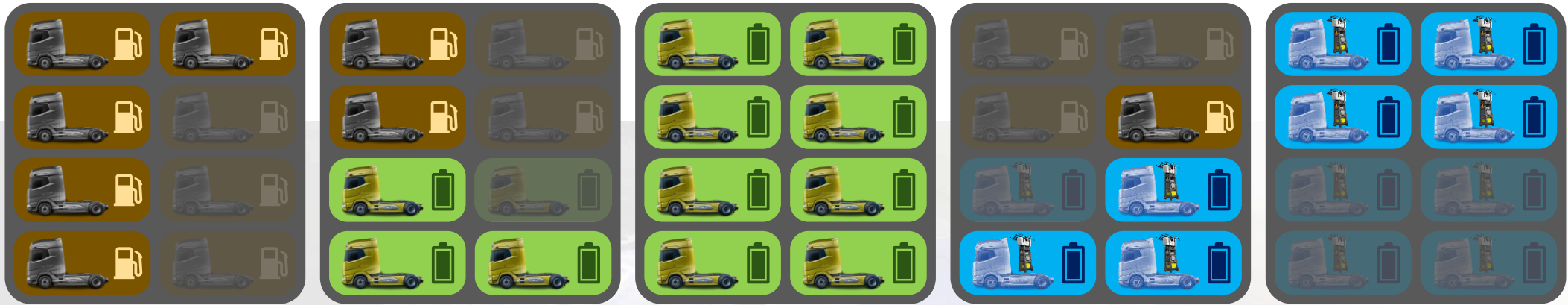
## Orders

-  20x A → B

## Vehicles

-  4x 26t-ICEV
-  4x 27t-OBEV





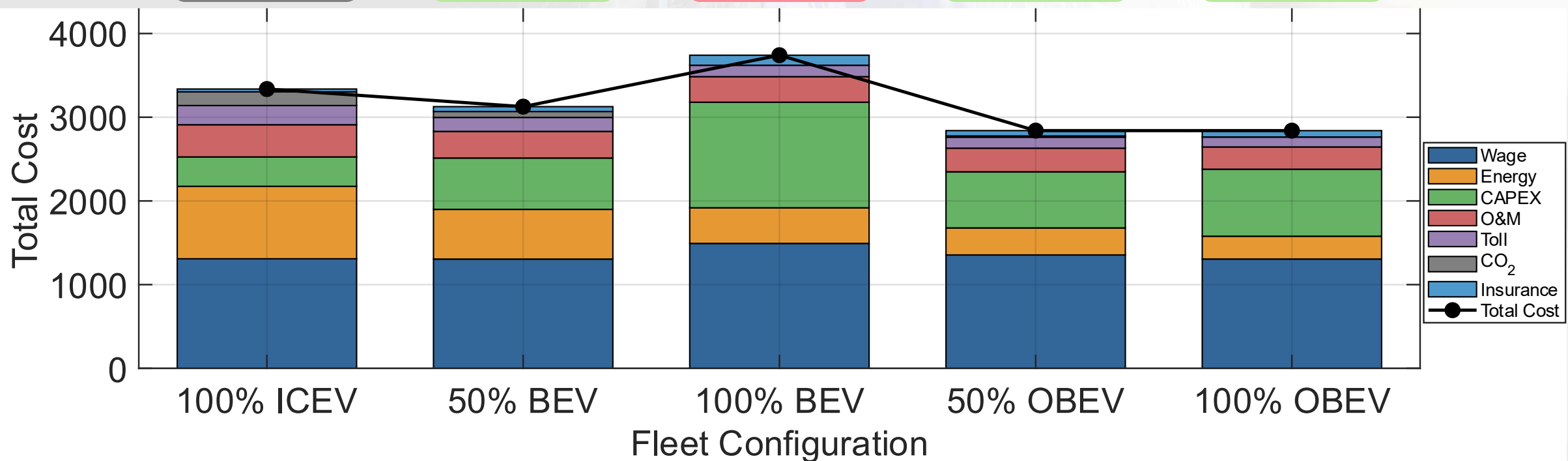
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▼14.9%



# Thank you for your attention!

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**BEE**  
BEV Goes eHighway



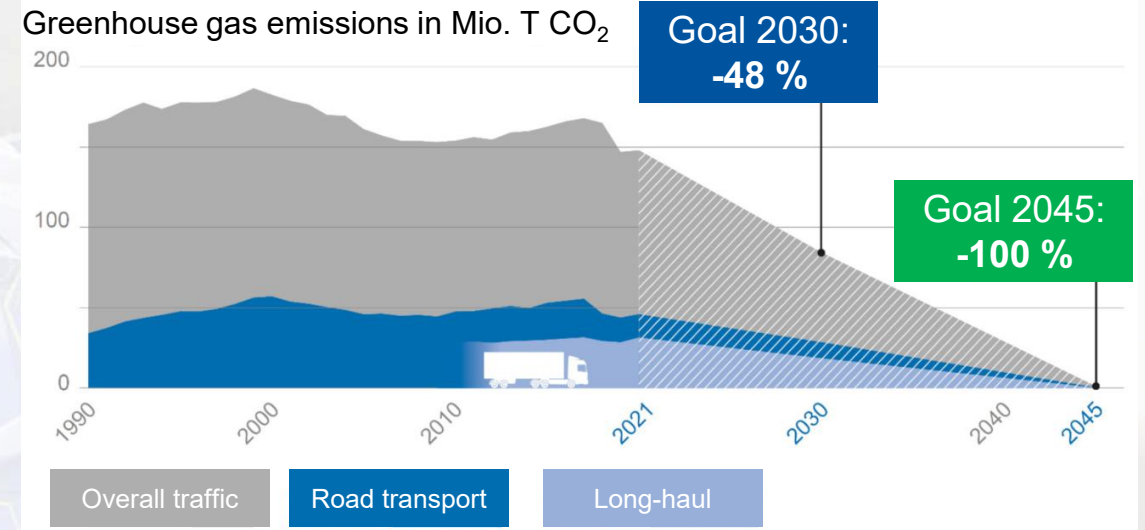
# TCO Analysis for Retrofitted Catenary Trucks

Hendrik Vorjans  
*RWTH Aachen*

# Market Characteristics

## Facts:

- 70.7 % of freight-transport with trucks
- Approx. 230,000 long-haul trucks in Germany
- Lifetime of 1 Mio. km
- 120,000 km yearly milage
- Sales of zero-emission trucks increasing at a low level (1.7 % in Germany 2024)

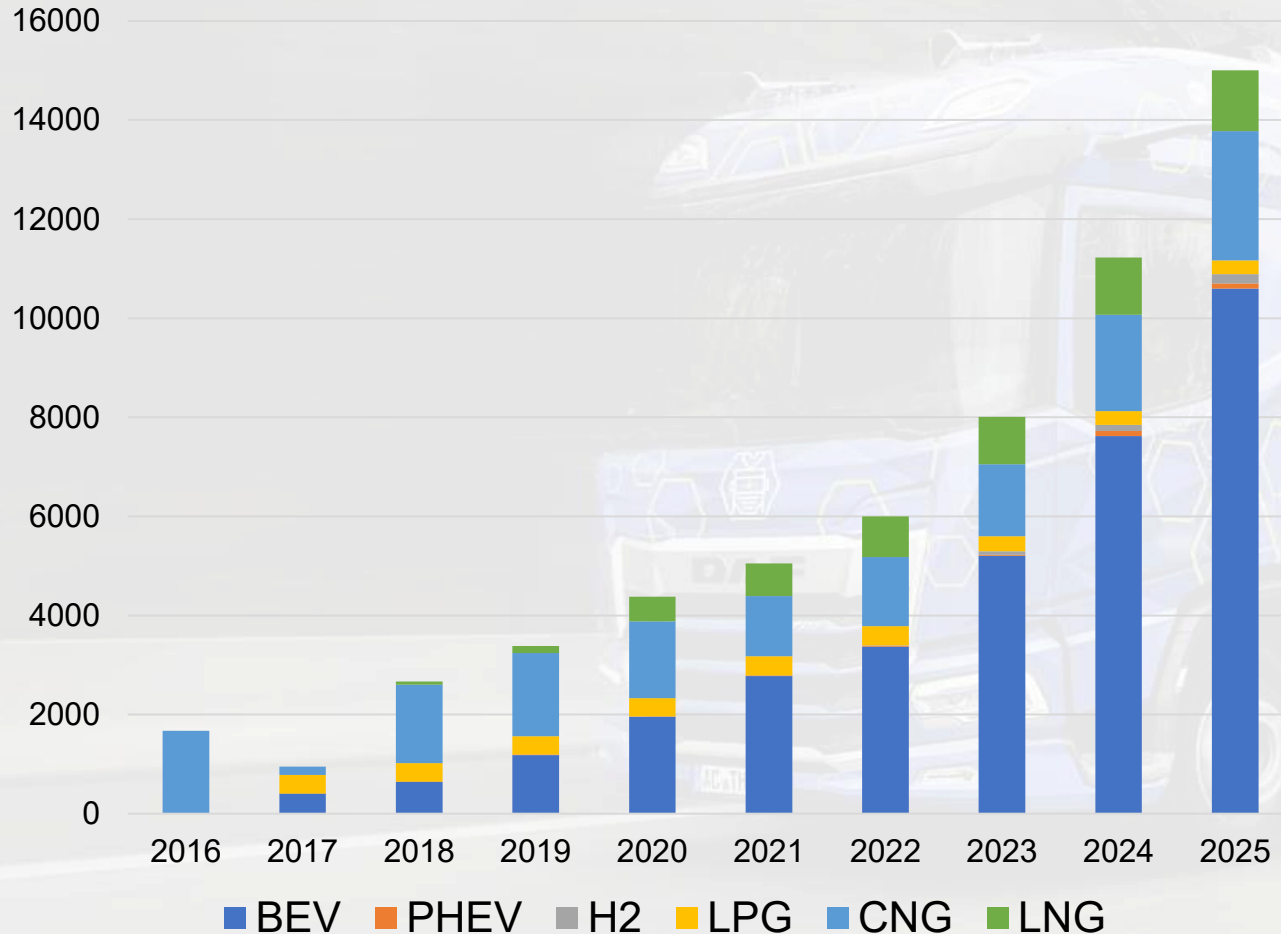


A bigger effort in Zero-Emission technologies is needed...

...and increasing political influence can be expected

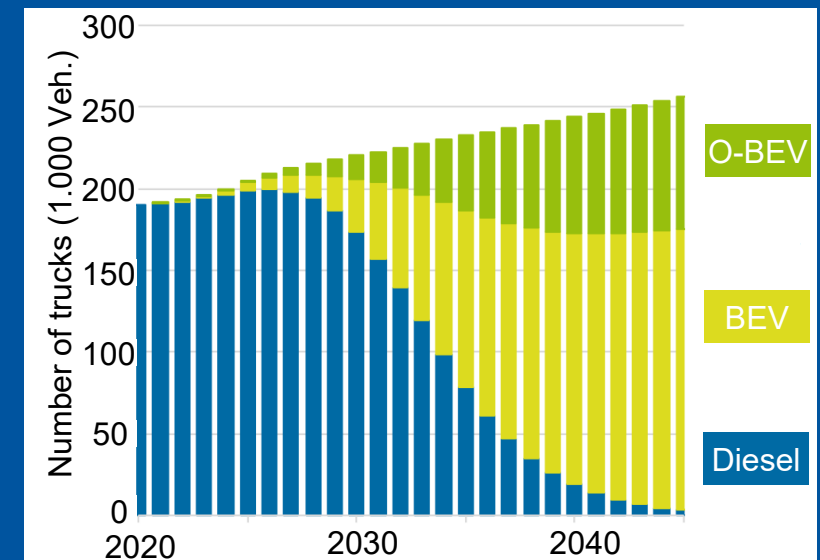
# Technology-Mix

Total number of alternative powertrains



Diesel trucks are still dominating the market with approx. 45,000 registrations per year.

How can a future with the catenary technology look like in 2035:



# Financial Fundamentals: Income-Loss Statement & TCO

## Income-Loss Statement

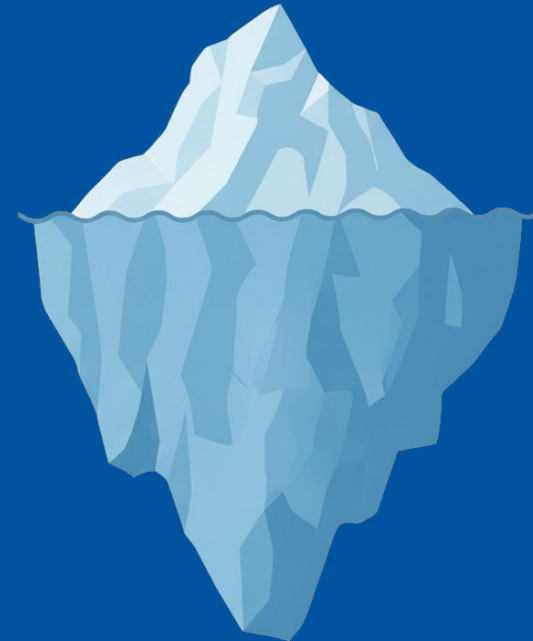
- Measurement of the company's financial performance over a specific period
- Shows how revenue translates into income and how to optimize profits

Typical elements:

- + Revenue
- Investment costs (CAPEX)
- Operational expenses (OPEX)
- Taxes and Depreciation
- Profit

## Total costs of ownership (TCO)

- While income is uncertain, the costs can be estimated and optimized



### Acquisition Price

- Purchase Price

### Hidden Costs

- Energy Costs
- Capital Costs
- Government Incentives
- Maintenance
- Taxes
- CO<sub>2</sub> costs

# Financial Fundamentals: Cash Flow & Net Present Value (NPV)

## Net Cash Flow

- Tracks movement of money to ensure liquidity
- not all expenditures have an immediate impact on my Cash-flow

### Elements of Cash Flow:

- Operating Cash Flow
- Investment Cash Flow
- Financing Cash Flow

→ Operating Cash Flow main focus

## Net Present Value (NPV)

Money now is worth more than money later

$$NPV = \frac{Cach\ flow(t)}{(1 + r)^t}$$

For example:

1000€ fuel costs in the future are cheaper than 1000€ today

→ **An investment is profitable, if NPV > 0**

# Strategic Planning: Sensitivity & Scenario Analysis

“Income is uncertain, costs can be estimated”... but how good is the estimation?

How to test our calculations and results:

## Sensitivity:



**Focus** on changing on factor  
(ceteris paribus)

**Goal:** Identifying critical drivers of the investment

For Catenary:  
Percentage of Catenary drive, electricity costs



## Scenarios:



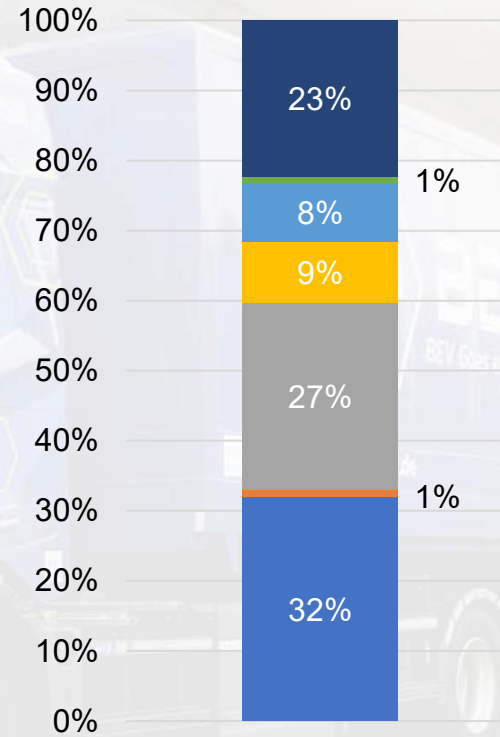
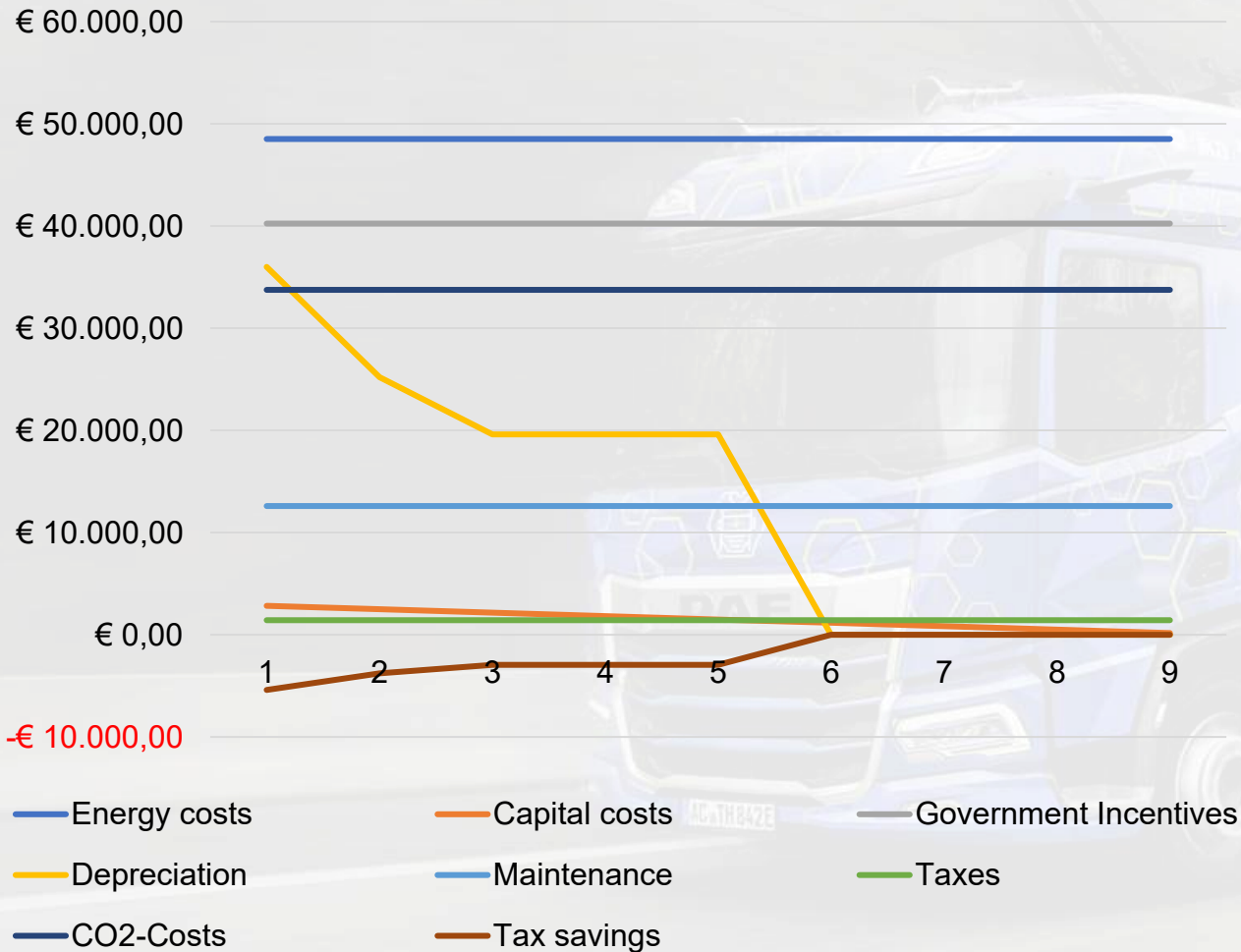
**Focus** on holistic approach by changing multiple factors

**Goal:** Evaluate risk and resilience of the investment

For Catenary:  
prioritize ERS, simultaneous technology support, no government support

# TCO of Diesel-trucks

Costs over Lifetime



## Assumptions:

- Long-Haul
- $m_{Max} = 40t$
- 120,000 km/year
- Diesel: 1.55 €
- Special depreciation
- 9 years lifetime

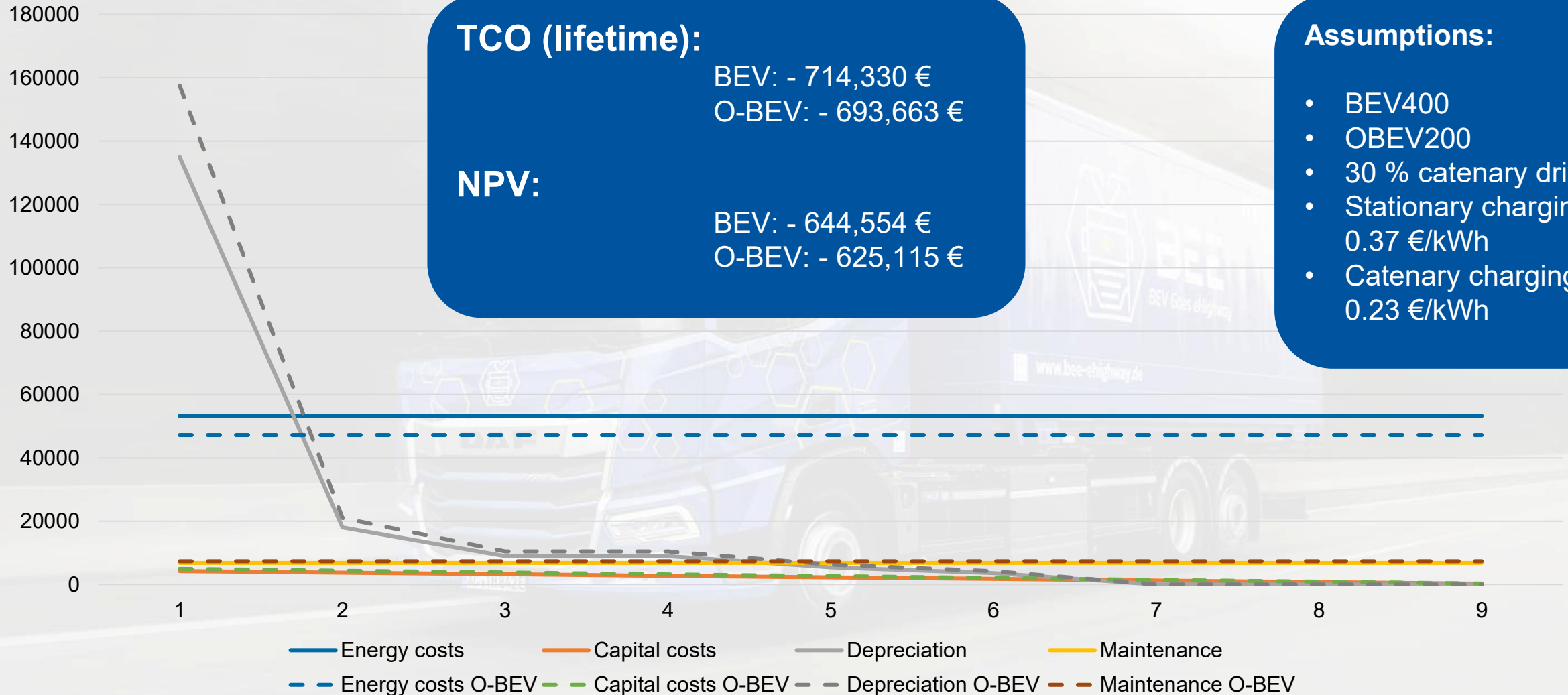
## TCO (lifetime):

- 1,344.,330€

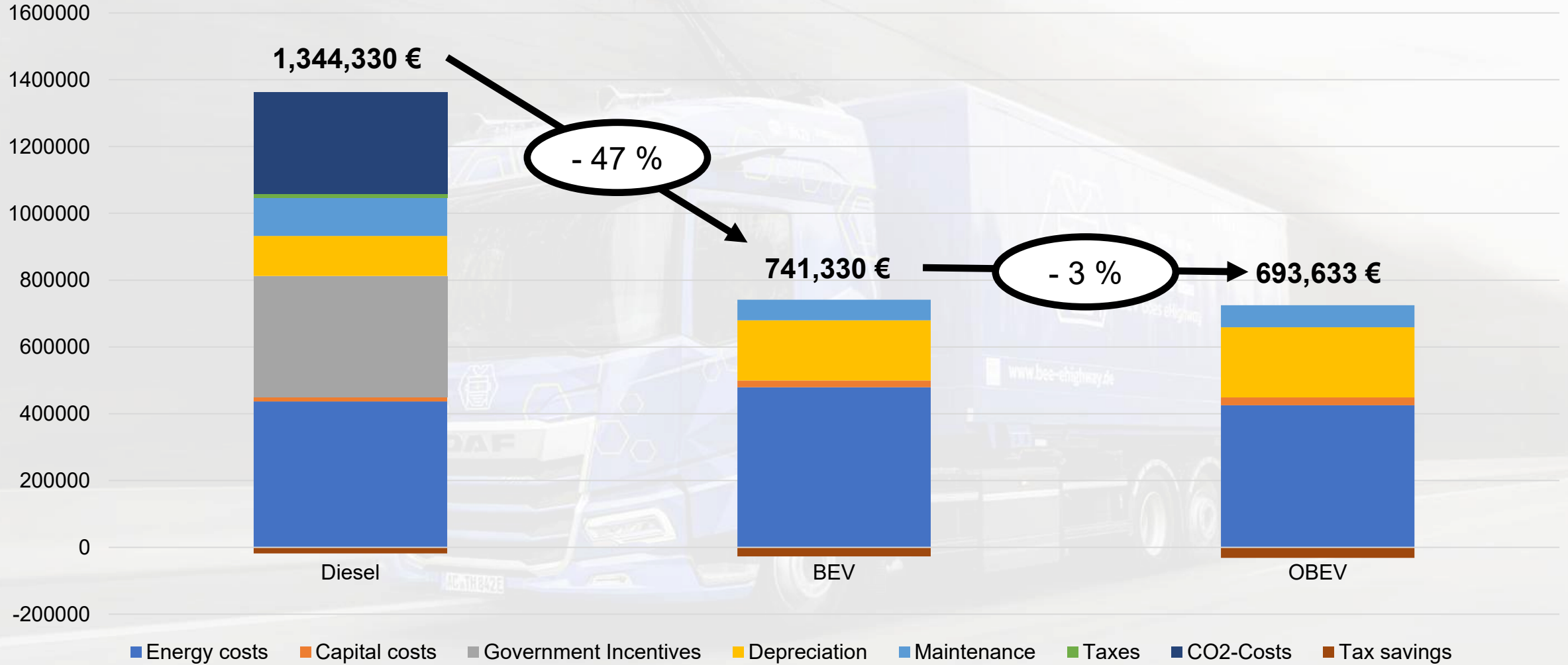
## NPV:

- 942,471 €

# TCO of BEV and O-BEV trucks



# Comparison of Diesel, BEV and O-BEV



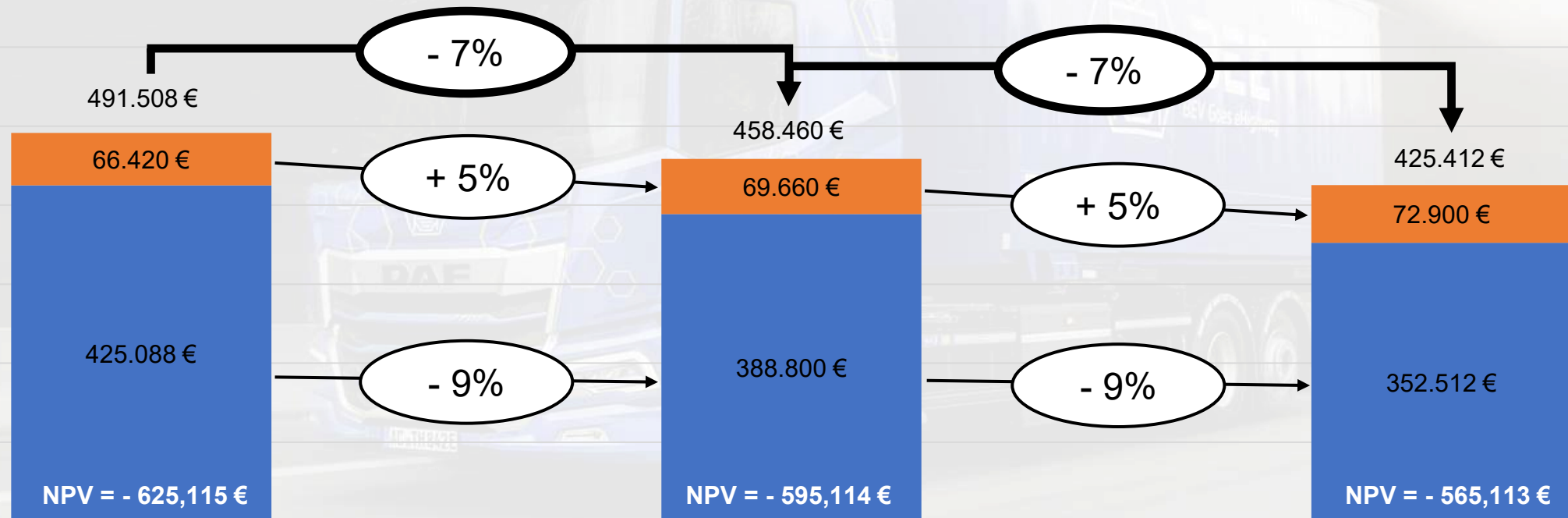
# Sensitivity analysis: Pull-factor catenary network

Assumption: Increase in catenary drive from 30 % to 50 % and 70 %

30 % catenary

50 % catenary

70 % catenary



■ Energy costs ■ Maintenance

# Sensitivity analysis: Pull-factor electricity price

Assumption: Costs of electricity under the catenary vary (with 30 % catenary)

20 % decrease

Status-quo

20 % increase

Energy costs  
- 4,2 %

Energy costs  
+ 4,2 %

**TCO (lifetime):**  
O-BEV: - 675,748 €

**NPV:**  
O-BEV: - 608,879 €

**TCO (lifetime):**  
O-BEV: - 693,663 €

**NPV:**  
O-BEV: - 625,115 €

**TCO (lifetime):**  
O-BEV: - 711,517 €

**NPV:**  
O-BEV: - 641,350 €

# Scenario technique

## No government support

All incentives regarding taxes, depreciation, tolls and CO<sub>2</sub>-pricing get canceled

**TCO (lifetime):**

O-BEV: - 1,115,616 €

**NPV:**

O-BEV: - 1,009,021 €

## Simultaneous technology support

A 30 % base catenary network is ensured but there no additional incentives in depreciation taxes or tolls

**TCO (lifetime):**

O-BEV: - 693,663 €

**NPV:**

O-BEV: - 625,115 €

## Prioritize ERS

Existing incentives stay, catenary network gets extended to 70 % and electricity prices drop 20 %

**TCO (lifetime):**

O-BEV: - 585,805 €

**NPV:**

O-BEV: - 527,230 €

# Wrap-Up and outlook

## Summary:

- There is a need for zero-emission technologies and government interference can be expected
- **BEV** trucks are under the current incentives **already competitive** with diesel trucks
- Diesel trucks are the main technology mainly because of **insufficient pricing of negative environmental effects**
- **O-BEV trucks are the most profitable technology if over 30 % catenary drive** can be ensured and electricity costs are lower under the catenary

## Field of action:

- It is important to build a **base-level catenary network** for catenary trucks to succeed
- While increasing the catenary network above 30 %, **low electricity costs can be a great push factor** for the technology during the transition phase

# Thank you for your attention!

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**BEE**  
BEV Goes eHighway



# Bidirectional ePTO

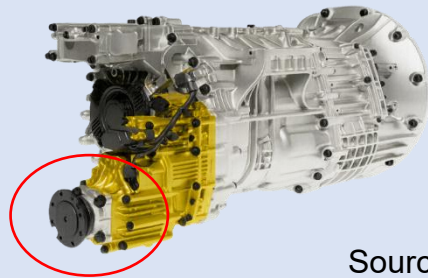
**Benedikt Siemons**  
*RWTH Aachen*

# Wat is 'n PTO?

## PTO

### Power Take-Off

- Mechanical Power Take-Off at a shaft
- Located at the Gearbox
- Drivetrain must run to use PTO
- While driving PTO speed is dependent to drive speed
- Easy to use for BodyBuilders



Source: Scania

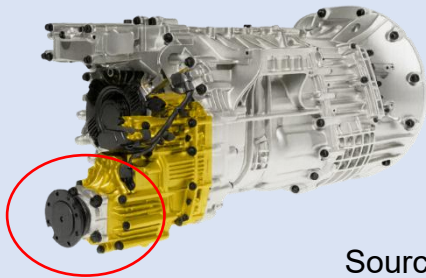


# PTO vs. ePTO

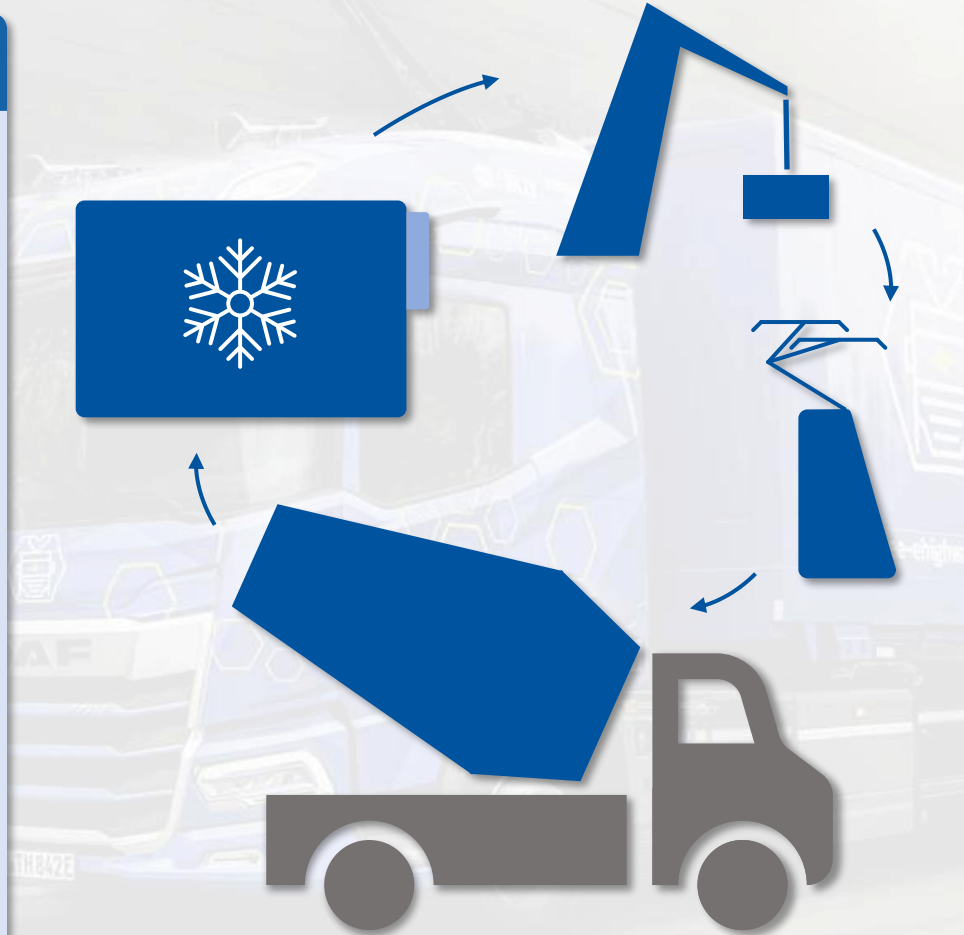
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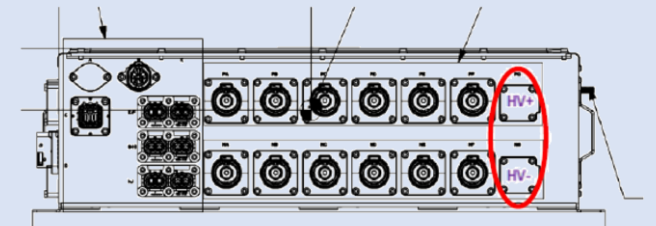
Source: Scania



## ePTO

### Electric Power Take-Off

- Connection to Vehicle HV System
- Electricity can directly be used by body
- Silent use of Body Functions
- CO<sub>2</sub> neutral use of Body
- Higher efficiency
- Higher degrees of freedom for BodyBuilder



Source: DAF

# Standardized Communication Needs



Currently a Standardized communication Protocol between Vehicle and Body is missing. This results in many different Problems



A standard similar to the CCS-Standard, which is used for charging, will simplify and accelerate the adoption of CO<sub>2</sub> neutral Vehicles



Electric Power



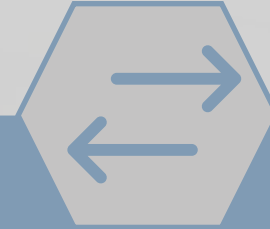
Safety



Source: Phoenix Contact

## ISO 15118

- Plug and Charge
- Communication between vehicle and charging station
- High level protocol layer for data exchange
- Secure and intelligent charging
- Easy to use for user and manufacturer
- Increases user acceptance of BEV vehicles



Bidirectional Use



Ease of use

Currently a Standardized communication

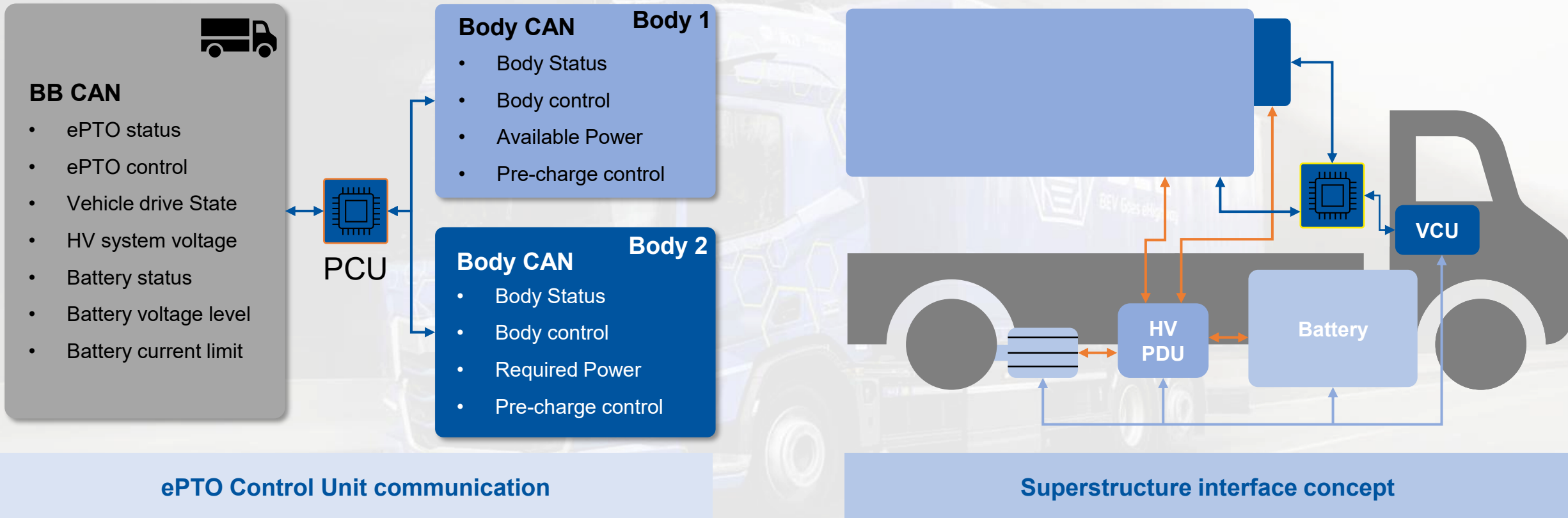
A standard similar to the CCS-Standard

This results in many different Problems

to generate the adoption of CO<sub>2</sub> neutral Vehicles



# PCU ePTO Control Unit



# Communication Strategies



## Software Standards

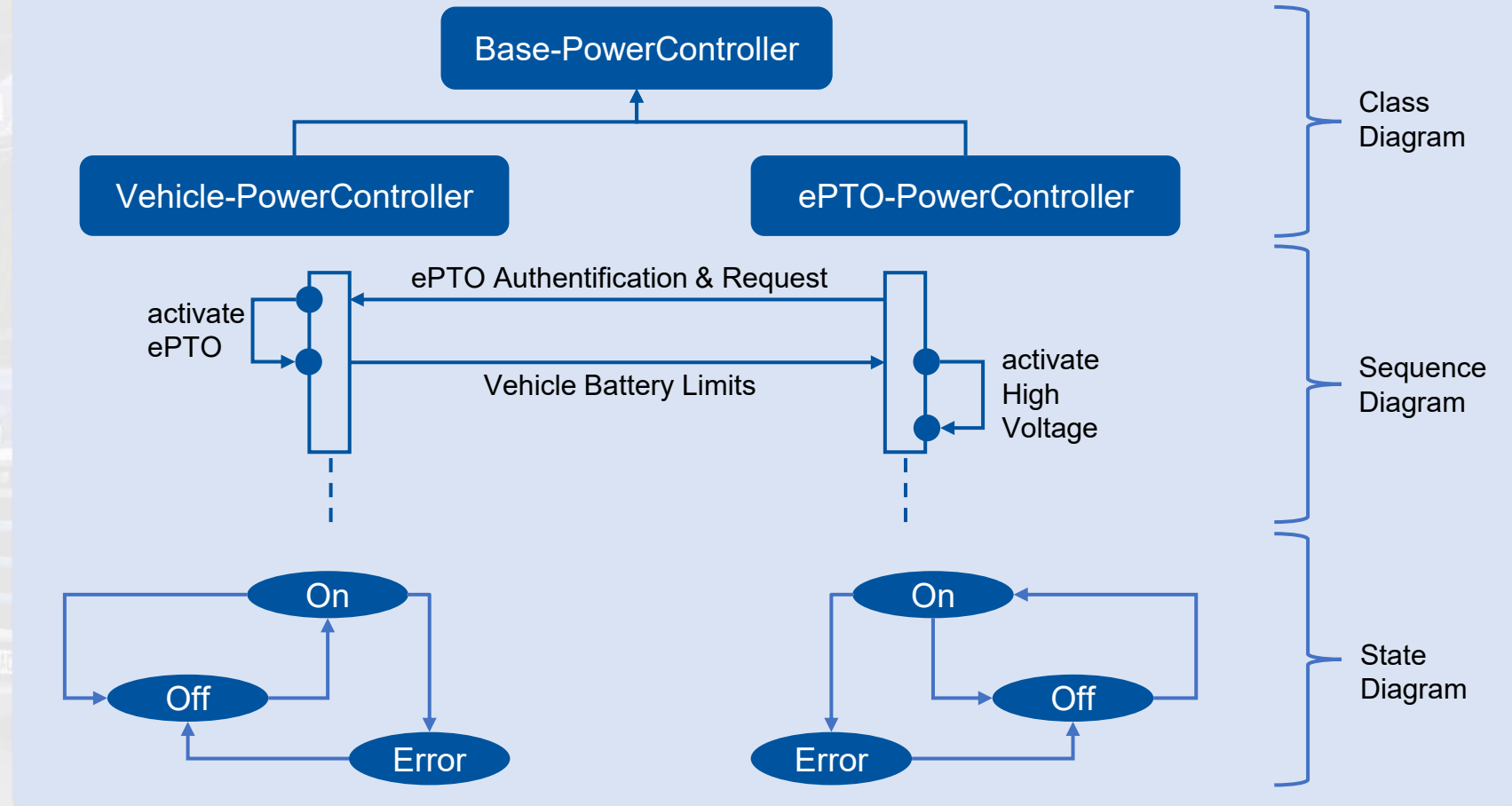
### SAE J1939 CAN FD

- Controller Area Network
- Flexible Data-Rate
- Higher bit rates than standard CAN

### CRC8-SAE-J1850

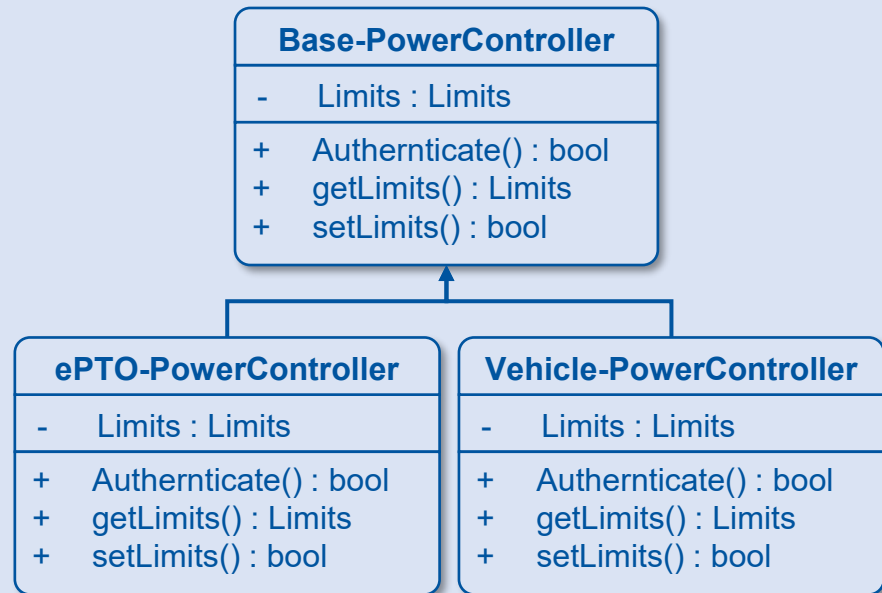
- Cyclic Redundancy Checks
- Checksum and counter
- Reliable and verifiable communication between vehicle and superstructure
- Meeting ISO26262 ASIL Levels

## Basic UML Implementation

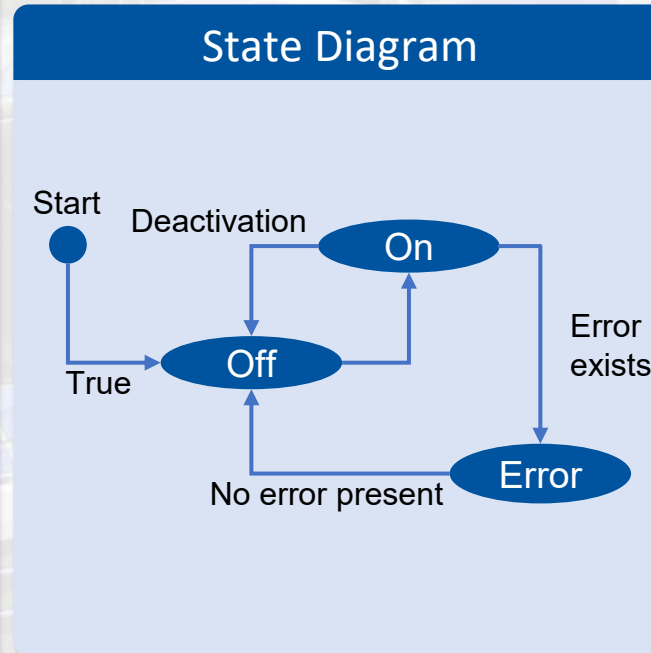


# Standardized Communication

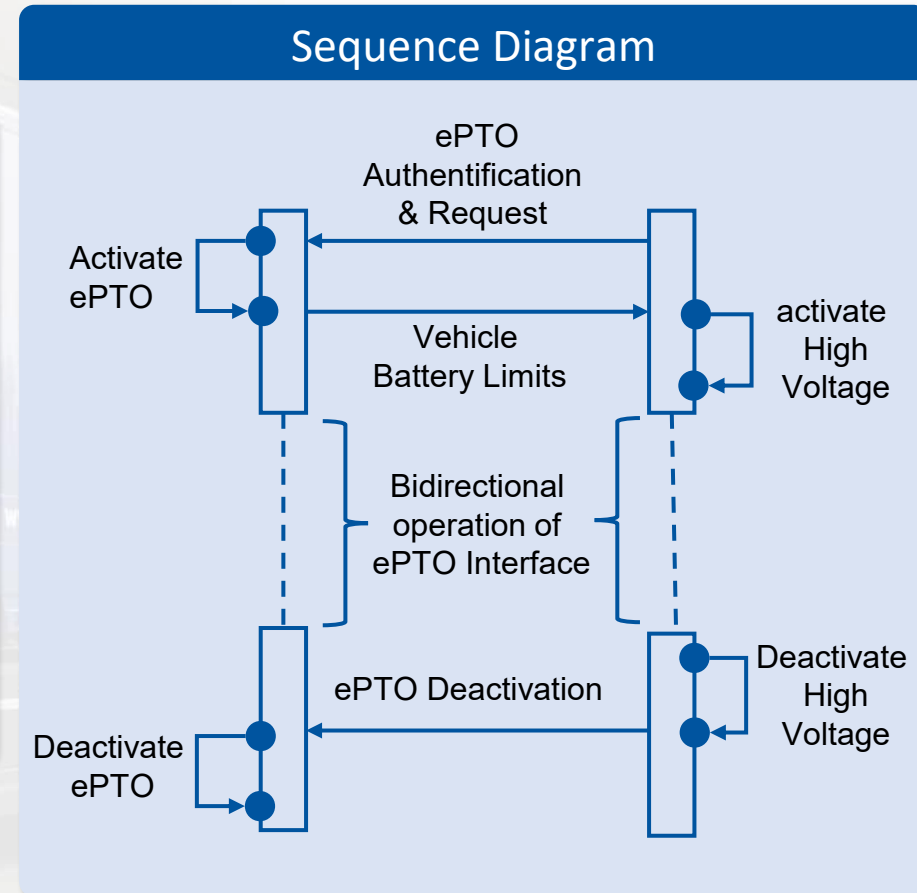
## Class Diagram



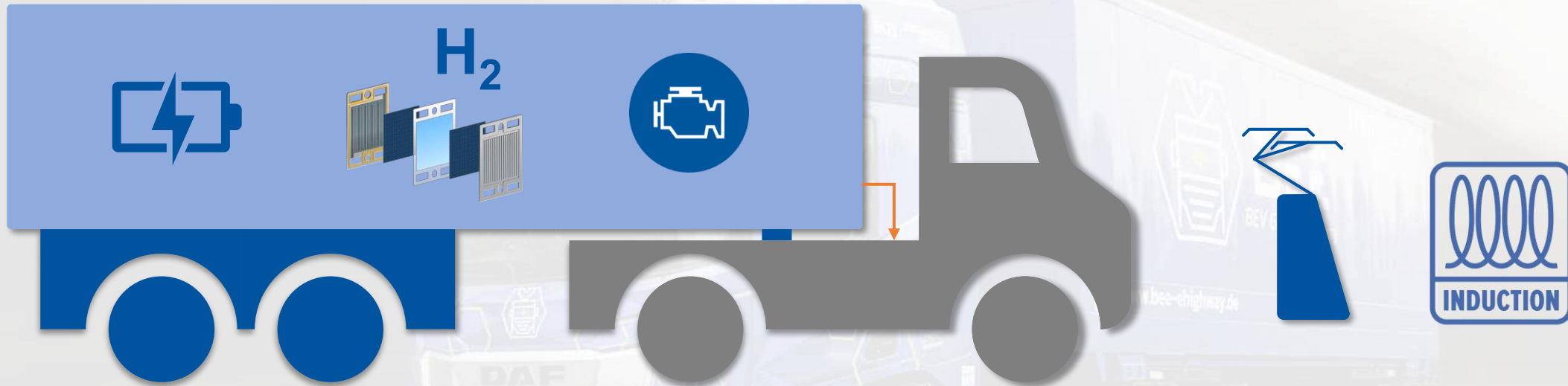
## State Diagram



## Sequence Diagram



# Opportunities of a bidirectional ePTO



A bidirectional ePTO enables the base vehicle's drivetrain to be extended by allowing the superstructure to charge the vehicle.



For decarbonized heavy-duty trucks, there is no “one-size-fits-all” solution. With an ePTO, a standard BEV can be adapted to the users' specific requirements.

# Thank you for your attention!



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