# Modeling synthetic load profiles of future e-truck charging hubs at service stations

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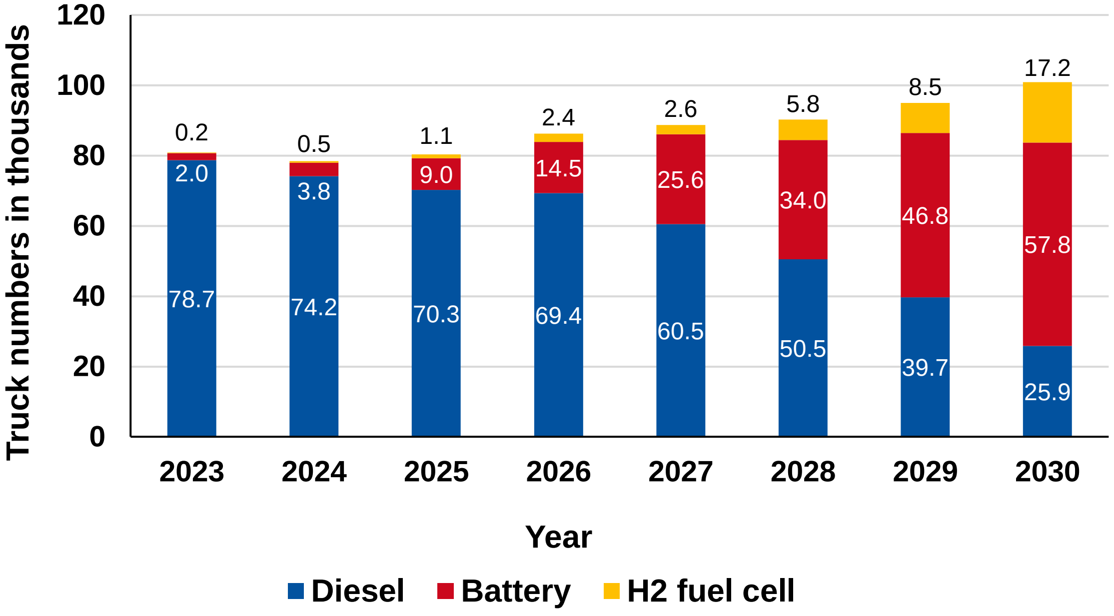
FCN | Future Energy Consumer Needs and Behavior
E.ON Energy Research Center
RWTH AACHEN UNIVERSITY

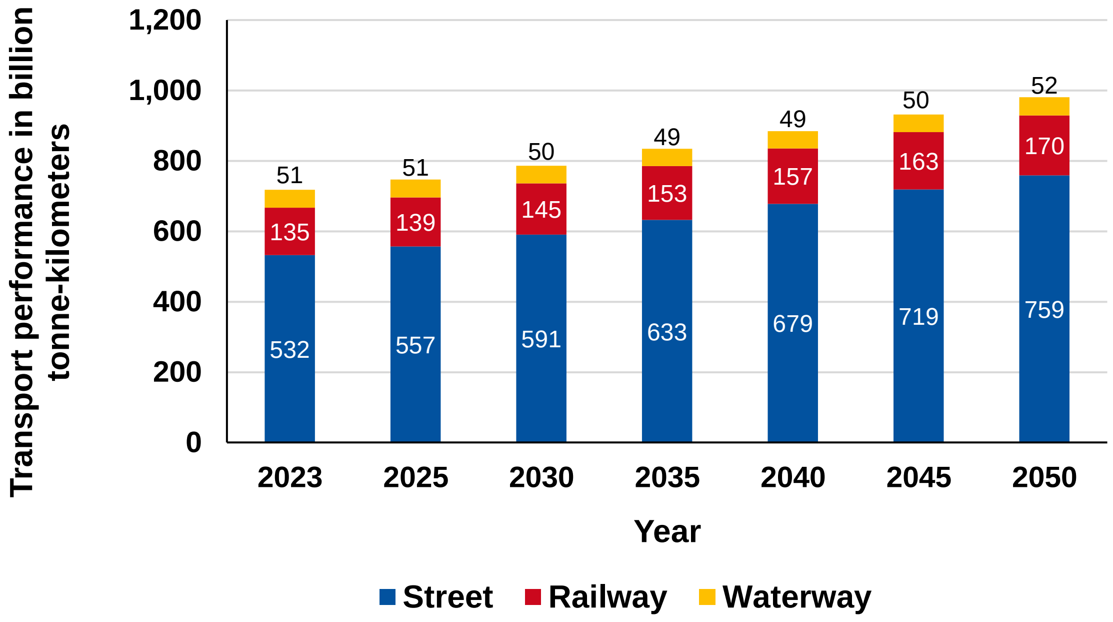
# Motivation
## Development of the share of battery-electric trucks and freight transport

**Forecast sales figures for heavy-duty vehicles (> 12 t) in Germany according to manufacturer data**




Source: Market development of climate-friendly technologies in heavy-duty road freight transport in Germany and Europe (2023). NOW GmbH.

**Forecast of the development of freight transport performance in Germany from 2023 to 2050**




Source: Gleitende Langfrist-Verkehrsprognose 2021-2022 (2023). Bundesministerium für Digitales und Verkehr, Intraplan Consult GmbH,TTS Trimode Transport Solutions GmbH

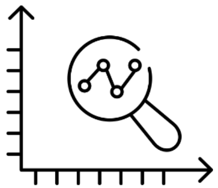
The **share of battery-electric heavy goods trucks** (sales forecast: 57 % in 2030) and **road freight transport** (+ 43 %  from now to 2050) will **increase** rapidly **in Germany** over the next few decades. **This will require a sufficiently dimensioned charging infrastructure at traffic hubs.**

# Research Questions
## Forecast of the load profiles of public charging hubs

### Influencing factors (selection)

- Overall **traffic flow**
- Development of the **e-truck drive** and **share**
- Dimensioning of the **charging infrastructure** and the service area
- **Aggregation** of individual charging processes
- **Charging management**

### Synthetic load profiles



### Benefits (selection)

- Design of **grid connection point** and charging hub **according to demand**
- **Optimization** of charging management
- Recognizing load peaks and **assessment of security of supply**
- **Emissions savings** in the utilisation phase of a Life Cycle Assessment (LCA)
- Calculation of **CAPEX**, **OPEX** and **revenues**
- Support for **grid expansion planning**

### Research Questions

1. How should a **methodology** for modeling synthetic load profiles for e-truck charging hubs be designed?
2. What **charging capacities** must charging hubs at **service stations** be equipped with in order to meet the demand from future traffic volumes depending on the location?
3. How much **greenhouse gas emissions** can electric truck charging hubs save in the future compared to diesel filling stations in the use phase alone?

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# Methodology
## Initialization of the charging hub

### Types of charging stations considered

**Megawatt Charging (MWC)**
Max. power: 1,000 kW
Max. Charging time: 45 min
06:00 am to 09:00 pm

**Night Charging (NC)**
Max. power: 150 kW
Max. Charging time: 480 min
09:00 pm to 06:00 am

**High Power Charging (HPC)**
Max. power: 350 kW
Max. Charging time: 45 min
06:00 am to 09:00 pm

**Low Power Charging (LPC)**
Max. power: 150 kW
Max. Charging time: 45 min
06:00 am to 09:00 am

- The charging hub of the service area has a defined number of each type of charging stations
- Depending on the arrival time, trucks are assigned a specific type of charging station

Initialization of the charging hub → Generation of arriving trucks → Assignment to free charging station → Charging management → Aggregation to load profile


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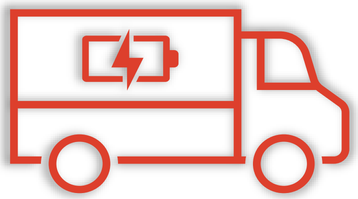
# Methodology
## Generation of arriving trucks



**Attributes of a heavy-duty e-truck**
- Cumulative energy quantity
- Loading time
- Parking time
- Battery status
- Capacity
- Charging station type
- Arrival time

**Example truck:**
**[0 kWh, 0 min, 0 min, 15 %, 504 kWh, "HPC„,1245 min]**

- Initialization with 0
- Randomly between 5 % and 30 %
- Selection based on defined frequency distributions
- Based on traffic flow

Initialization of the charging hub
↓
Generation of arriving trucks
↓
Assignment to free charging station
↓
Charging management
↓
Aggregation to load profile



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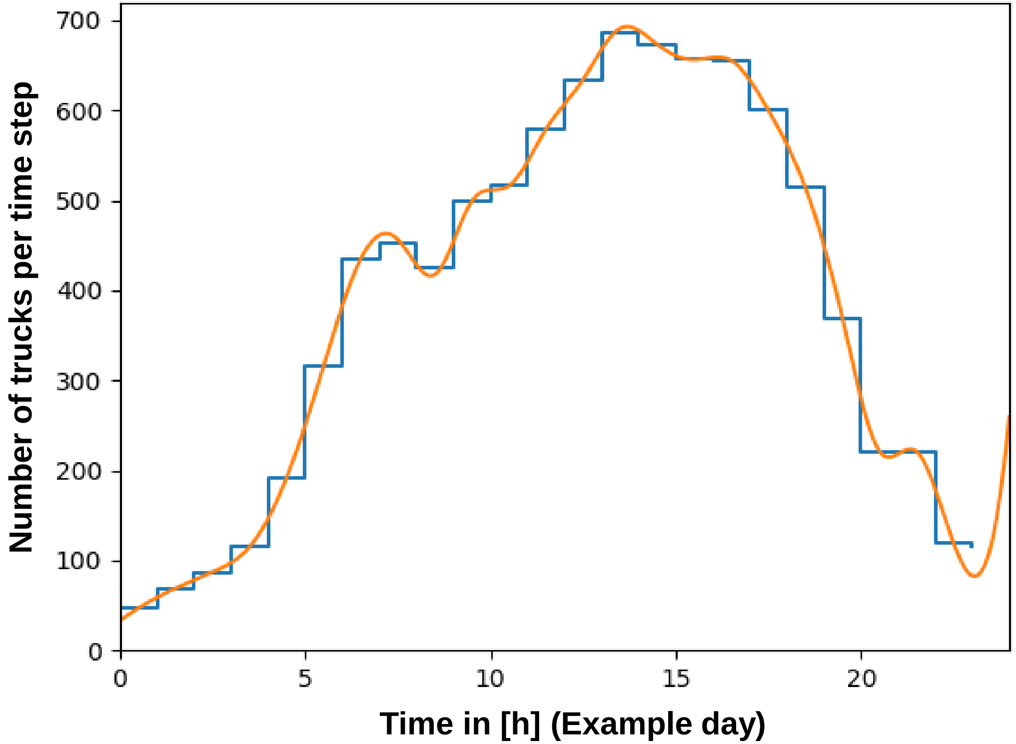
# Methodology
## Generation of arriving trucks

Bundesanstalt für Straßenwesen

**Basis: Traffic data** from automatic permanent counting stations from BASt on highways in Germany




**Database for arrival time**

- Dissolved hourly
- Differentiation by vehicle class
- For both directions of travel
- Support year: 2021

- Cubic approximation
- Progression between the hours
- Continuous, differentiable function

1. Initialization of the charging hub
2. **Generation of arriving trucks**
3. Assignment to free charging station
4. Charging management
5. Aggregation to load profile





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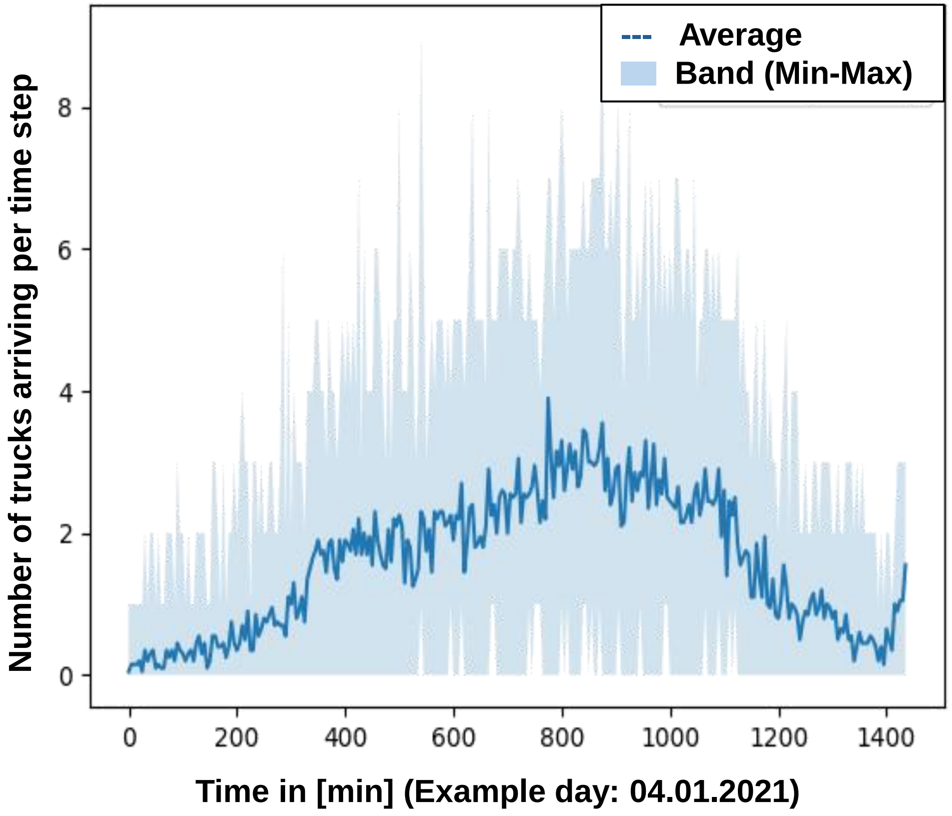
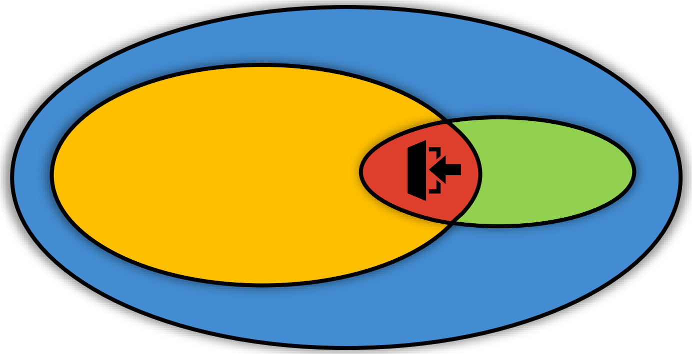
# Methodology
## Generation of arriving trucks

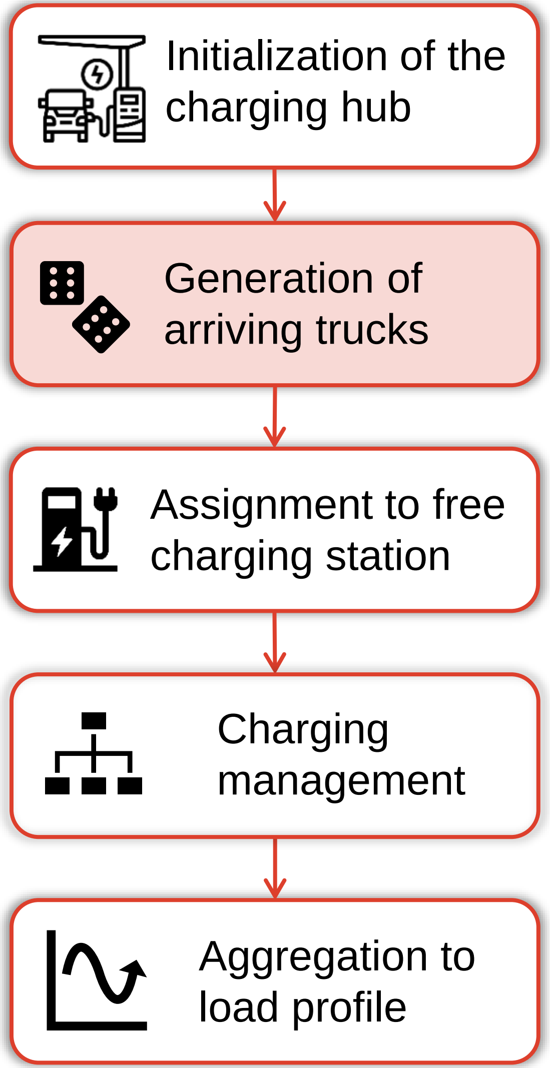
### Arrival time at service area: probability of turning into the service station




- **Total heavy goods traffic**
- **Share of battery-electric trucks**
- **Dynamic „turn-off probability over the day between 0 and 5 %**
- **Proportion of e-trucks with sufficient discharged batteries**



→ Monte-Carlo-Simulation
→ Input data for load simulations



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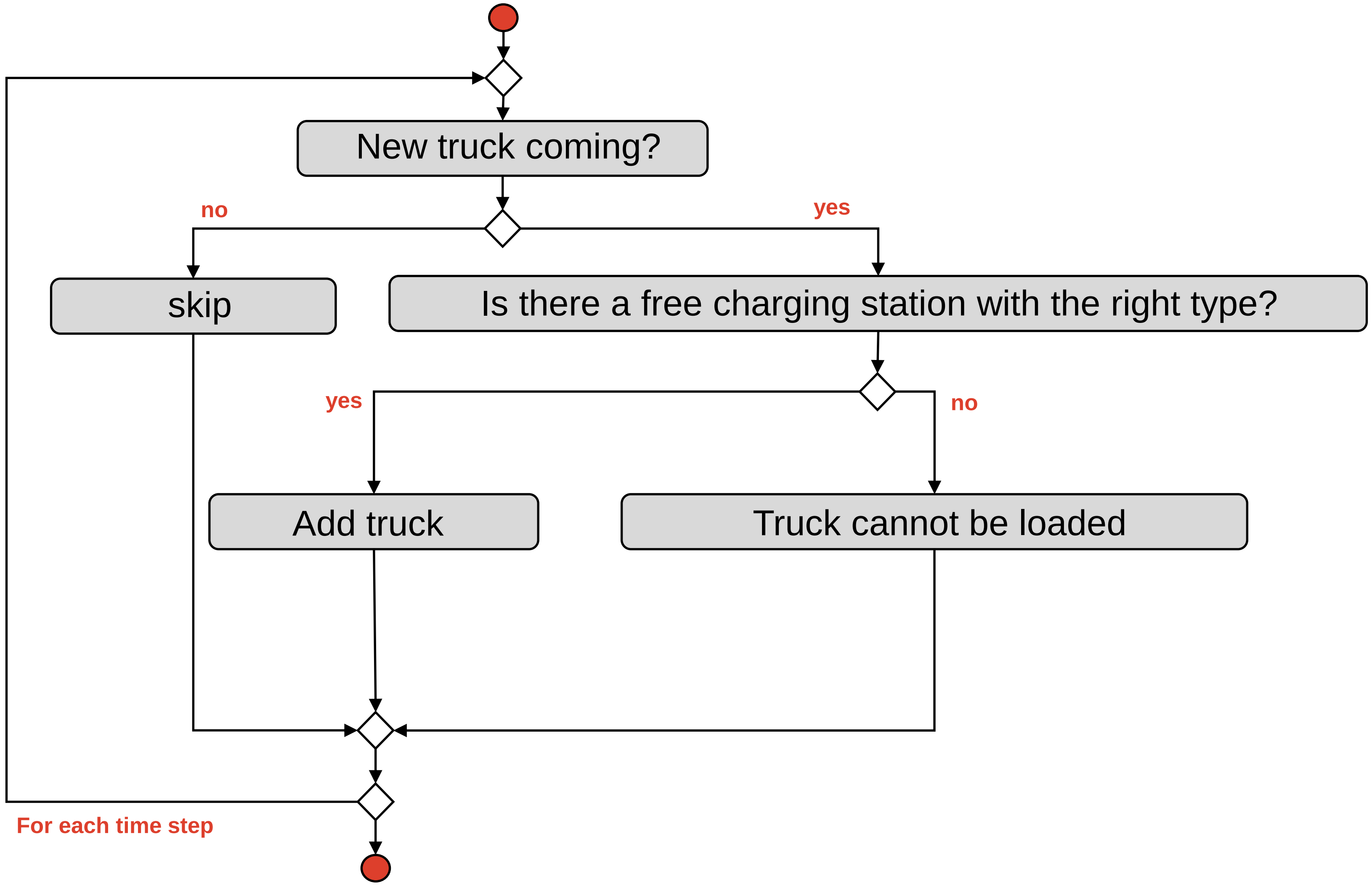
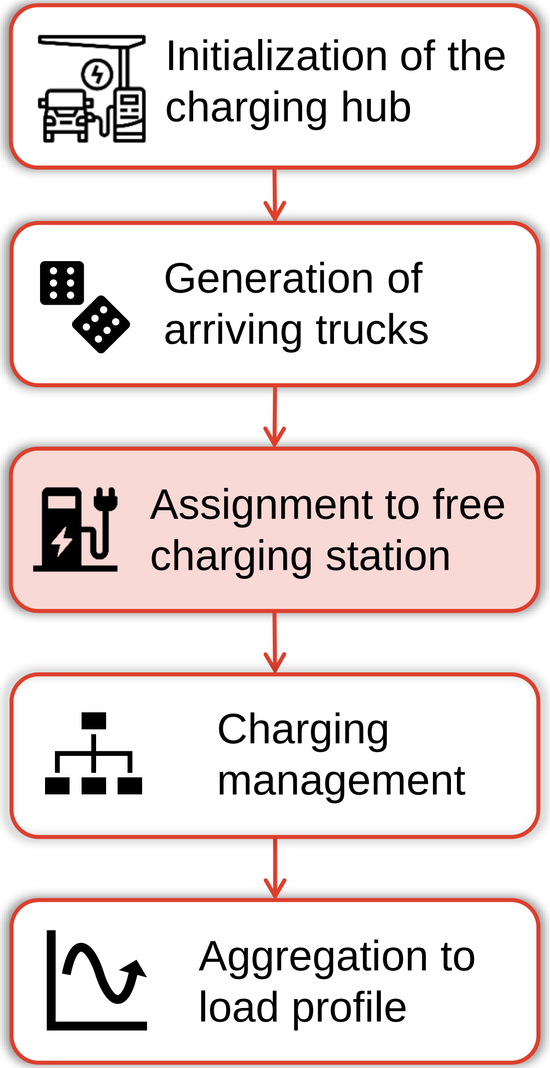
# Methodology
## Assignment of trucks to free charging station







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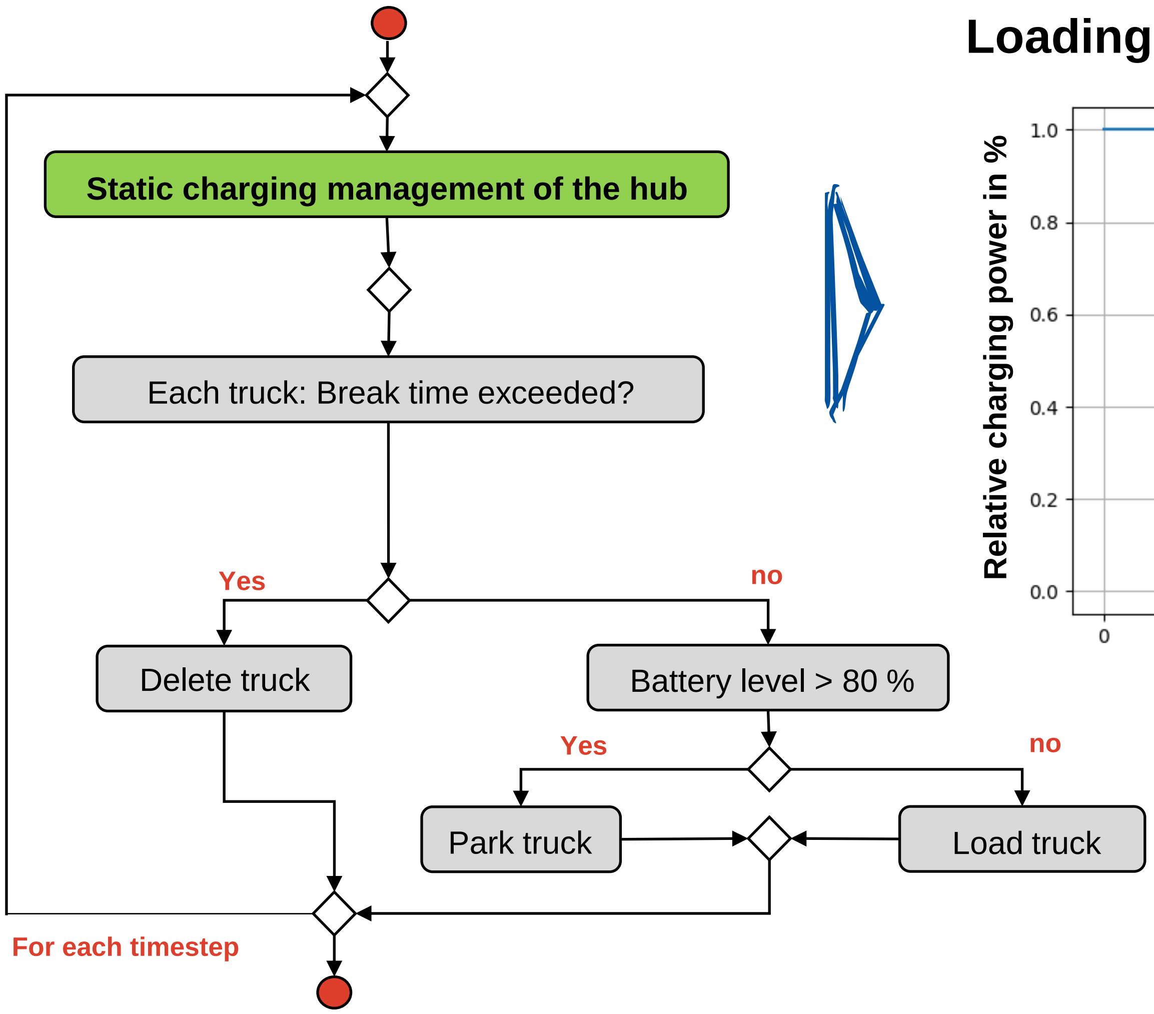
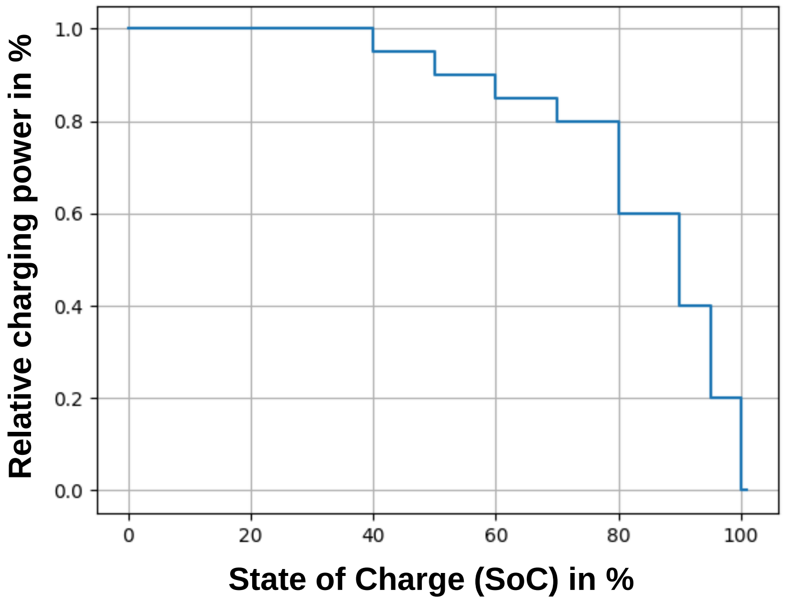
# Methodology
## Loading the arriving truck – charging management




### Loading curve for each truck




- Initialization of the charging hub
- Generation of arriving trucks
- Assignment to free charging station
- Charging management
- Aggregation to load profile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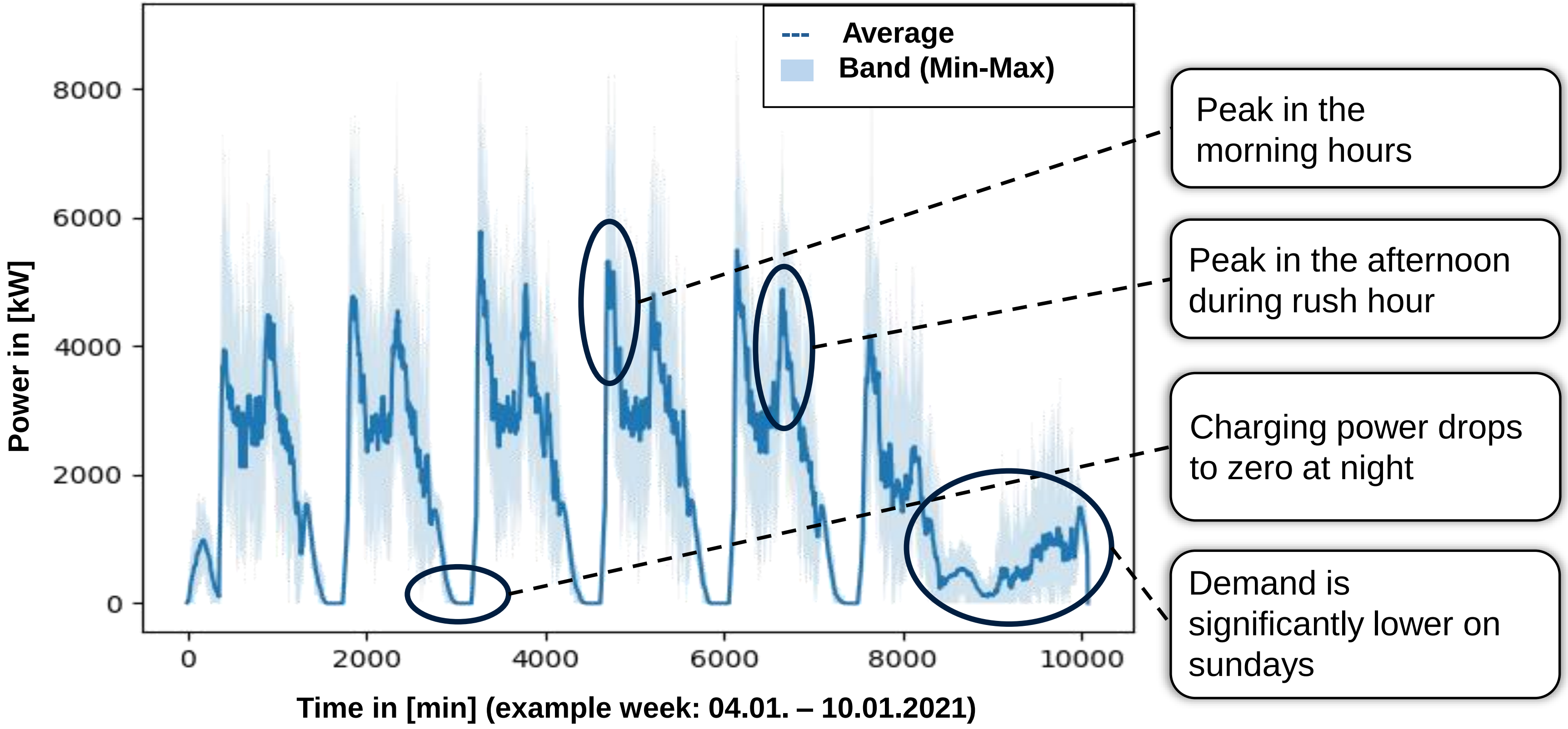
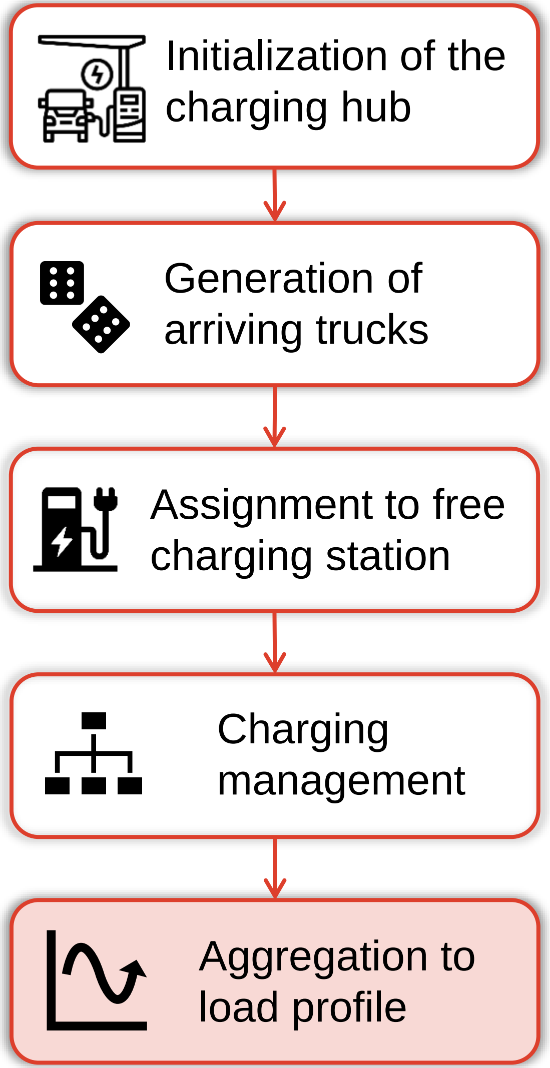
# Methodology
## Aggregation to load profile




- Addition of all charging processes of the charging stations in every time step of the simulation to one load profile
- Simplified onsideration of power losses between charging stations and grid connection point depending on components and grid topology





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# Results
## Definition of scenario

### Expansion of charging hub

| | Small | Medium | Large |
|---|---|---|---|
| NC | 6 | 16 | 32 |
| HPC | 5 | 11 | 23 |
| LPC | 6 | 16 | 32 |
| MWC | 2 | 5 | 11 |

- Orientation at „**Aachener Land**“ service area near Aachen highway junction: **130 truck parking spaces**
- **Average number of trucks per day: 12,858** (both directions together)
- Assumptions for expansion: Share of charging stations compared to parking spaces:

  → Small: 10 %, Medium: 25 %, Large: 50 %

### Overall traffic development

| | 2025 | 2035 | 2045 |
|---|---|---|---|
| **Increase in traffic** | **+7,2%** | **+22,4%** | **+33,6%** |
| **Share of e-trucks** | **4,9%** | **48,1%** | **83,7%** |
| Truck (252 kWh) | 42,3% | 58,4% | 60,3% |
| Truck (504 kWh) | 41,0% | 34,8% | 30,7% |
| Truck (756 kWh) | 16,7% | 6,7% | 9,1% |

Source: Own calculations and Göckeler et al. (2023): StratES – Szenarien für die Elektrifizierung des Straßengüterverkehrs. Studie auf Basis von Markthochlaufmodellierungen. StratES. Berlin: Öko-Institut e.V.


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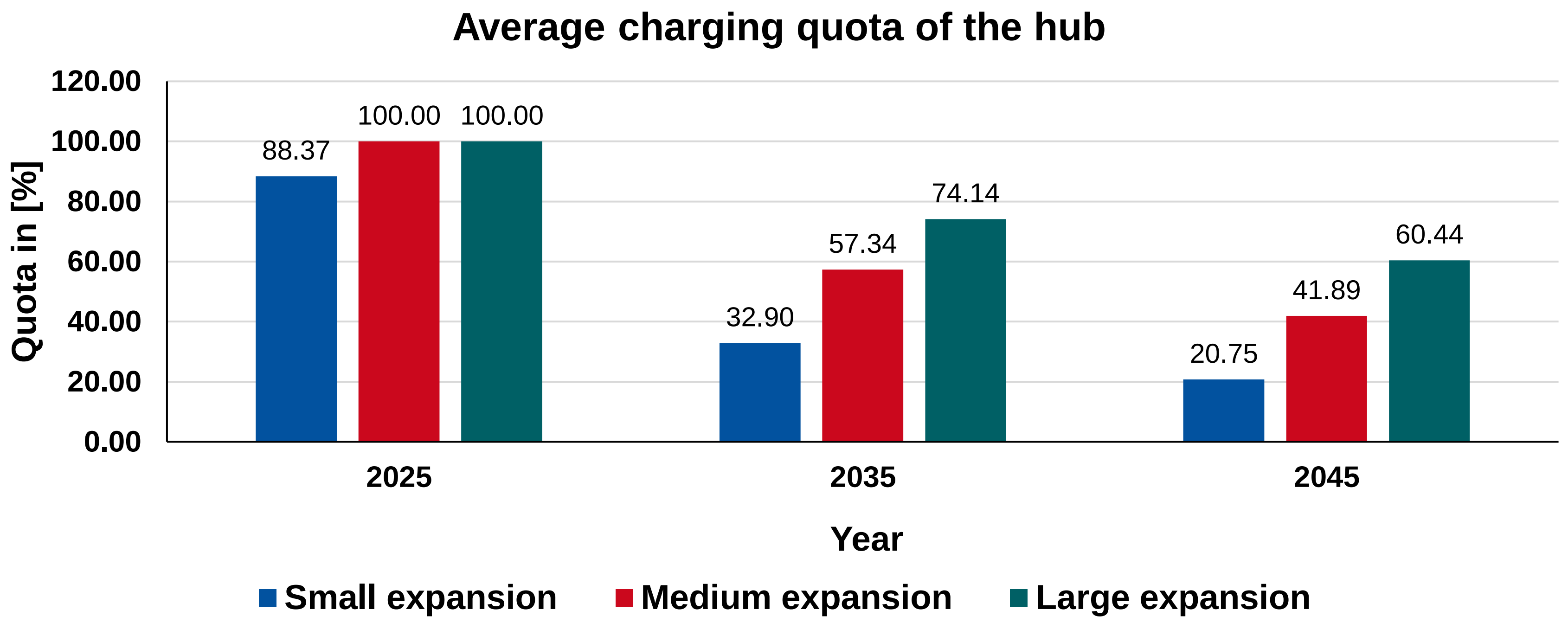
# Results
## Scenario: Charging quota




$$\text{Charging quota} = \frac{\text{Loaded trucks}}{\text{Total trucks}}$$

- Even before **2035**, it will **not be sufficient** for many service stations at transport hubs to equip **half of all parking spaces** with charging stations for e-trucks in order to **fully meet the demand** for electrical energy.
- **A Germany-wide guiding system** for the charging process of e-trucks and a **larger number of parking spaces** on the highway network will therefore be essential.

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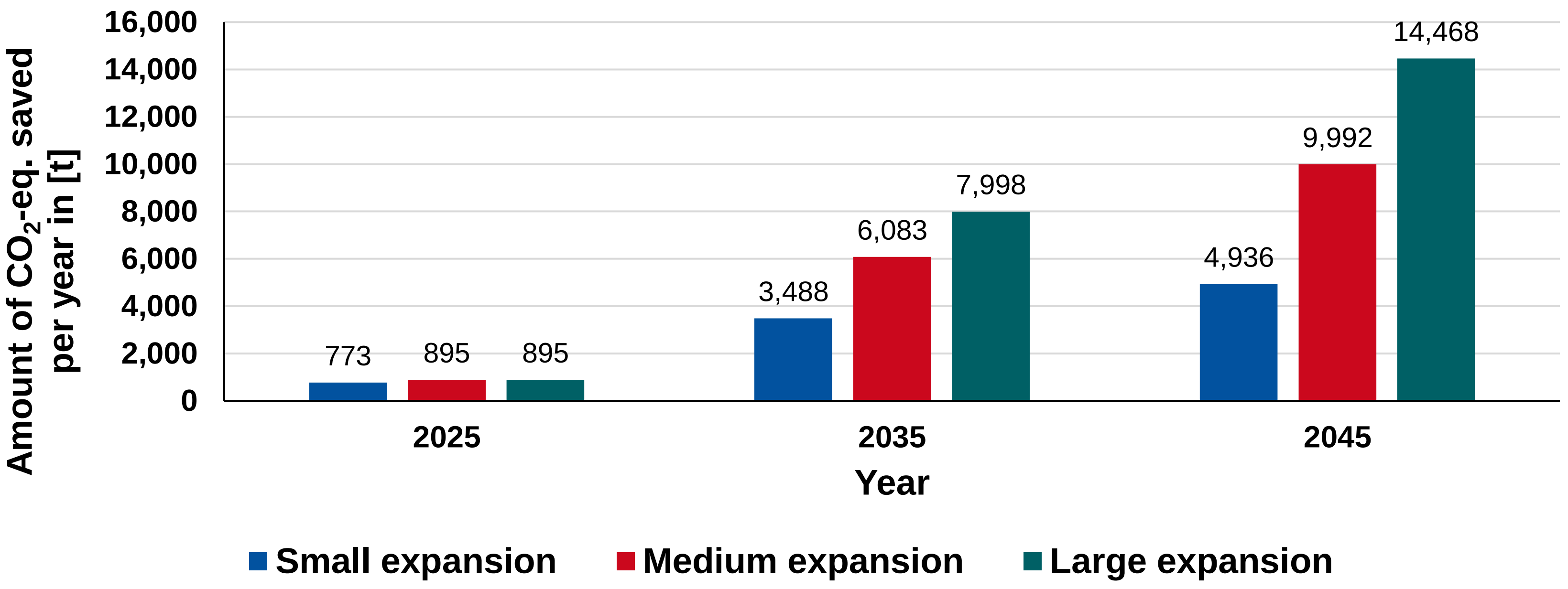
# Results
## Scenario: Greenhouse gas emissions saved by service station

### Comparison of GHG emissions from e-trucks compared to diesel trucks




- In the large expansion scenario, approx. **15,000 tonnes of CO2-eq. per year** can be saved with one service area in 2045.
- The **savings potential increases sixteenfold (x16)** by 2045 with a high share of renewable energies and a high share of e-trucks.

**Assumptions emission intensity electricity mix Germany:**

- **2025: 241 g $CO_2$-eq./kWh**
- **2035: 158 g $CO_2$-eq./kWh**
- **2045: 72 g $CO_2$-eq./kWh**

**Simulted with JERICHO Electricity Market Model from our chair FCN-ESE**

**Other Assumptions:**

- $CO_2$ factor diesel: 266 g/kWh
- Specific energy, electricity: 1.26 kWh/km
- Specific energy, diesel: 2.94 kWh/km
- Diesel- and e-trucks travel the same distance



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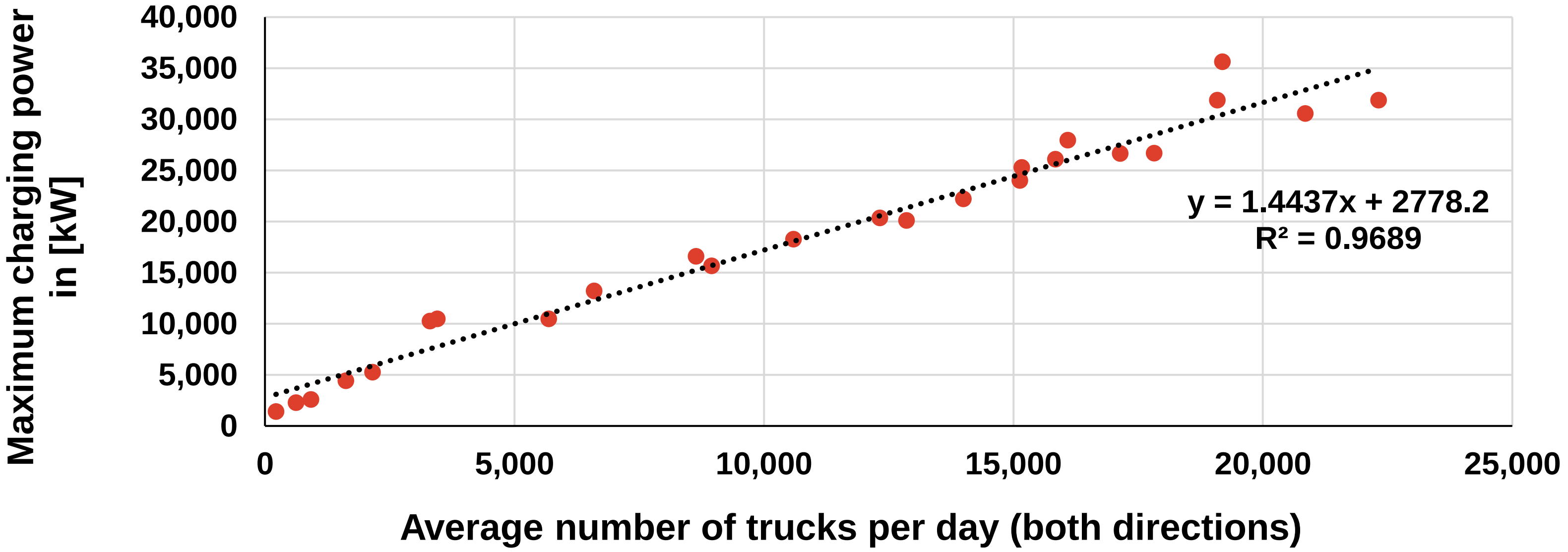
# Results
## Maximum charging power of future service stations

### Analysis of 25 locations of highway service stations across Germany in 2045




**Assumptions:**

- Necessary expansion of the charging hub for a **charging quota of 1**
- **Scenario data from year 2045**

- **Strong linear correlation** between the **maximum charging power** and the **traffic volume** at the highway location of a service station
- **Dynamic charging management** must reduce the maximum power at the grid connection point without reducing the charging rate → **High-voltage connection** still necessary at most future highway service stations

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# Key Takeaways and Outlook

## Key Takeaways

- **Rapid expansion of charging infrastructure and parking spaces** for e-trucks at highway service stations necessary until 2045
- A realistic equipment of **half of all truck parking spaces** in 2045 **will not be enough** to meet the demand
- In the large expansion scenario, approx. **15,000 tonnes of CO2-eq. per year** can be saved with one service station in 2045 (x16)
- Highway service stations on **busy roads** require a **high-voltage connection** with a grid connection capacity of approx. **20 - 40 MW** by 2045 (**linear correlation**)

## Outlook

- **Further development of the model:**
  - **Waiting places** (bridging the time until a charging station becomes available)
  - Exact location-specific **turning probability**
  - Intelligent (dynamic) charging management
  - Integration of **PV system** and **battery storage**
- **Optimization model** for planning support: Potential savings in the area of costs and emissions over entire life cycle
- **Exact prediction of grid utilization** by highway service stations for DSOs and TSOs
- **Germany-wide guiding system** for the charging process of e-trucks in order to optimally cover the demand



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# *Thank you for your attention!*

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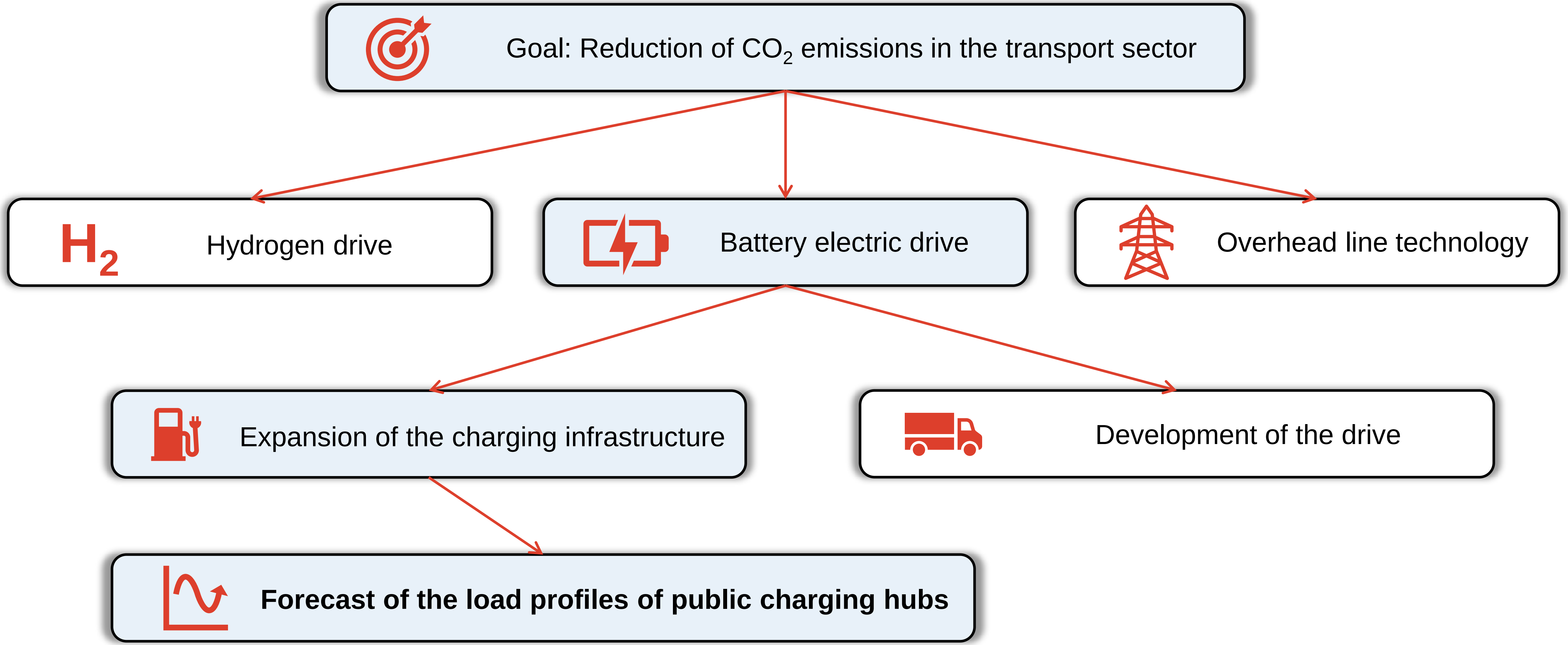
IDEAL

# Motivation
## Thematic classification of our research









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