

University of Stuttgart
Institute of Automotive Engineering

DAIMLER TRUCK

Multi-Objective Optimization of Electric Drivetrains regarding Commonality Aspects for Diverse Truck Portfolios

Philip Hätscher^{1,2}, Sven Köller¹, Sven Schulze¹, Sebastian Haudek¹, Carola Otto¹,
André Casal Kulzer²

¹Daimler Truck AG

²IFS, University of Stuttgart

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BHARATBENZ



Agenda

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- 01** | **Introduction**
Background and Portfolio Development
- 02** | **New Methodology for Drivetrain Platform Design for Electrified Truck Portfolios**
Modular Principle, Component Variation, and Multi-Objective Optimization
- 03** | **Exemplary Platform Optimization for Electrified Truck Portfolio**
Energy Consumption vs. Cost and Analyzing Communalities
- 04** | **Summary and Outlook**
Platform Methodology and Validation

Agenda

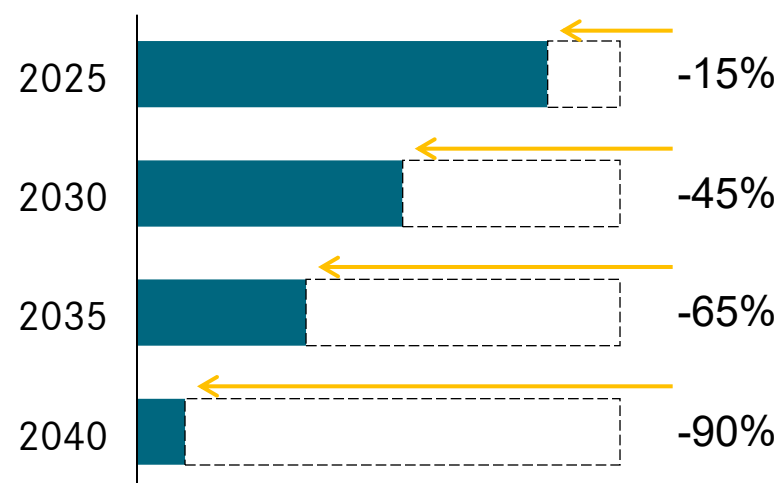


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CO₂-limits for Heavy-Duty Trucks result in further enhancement of electric portfolio through electric drivetrain platform

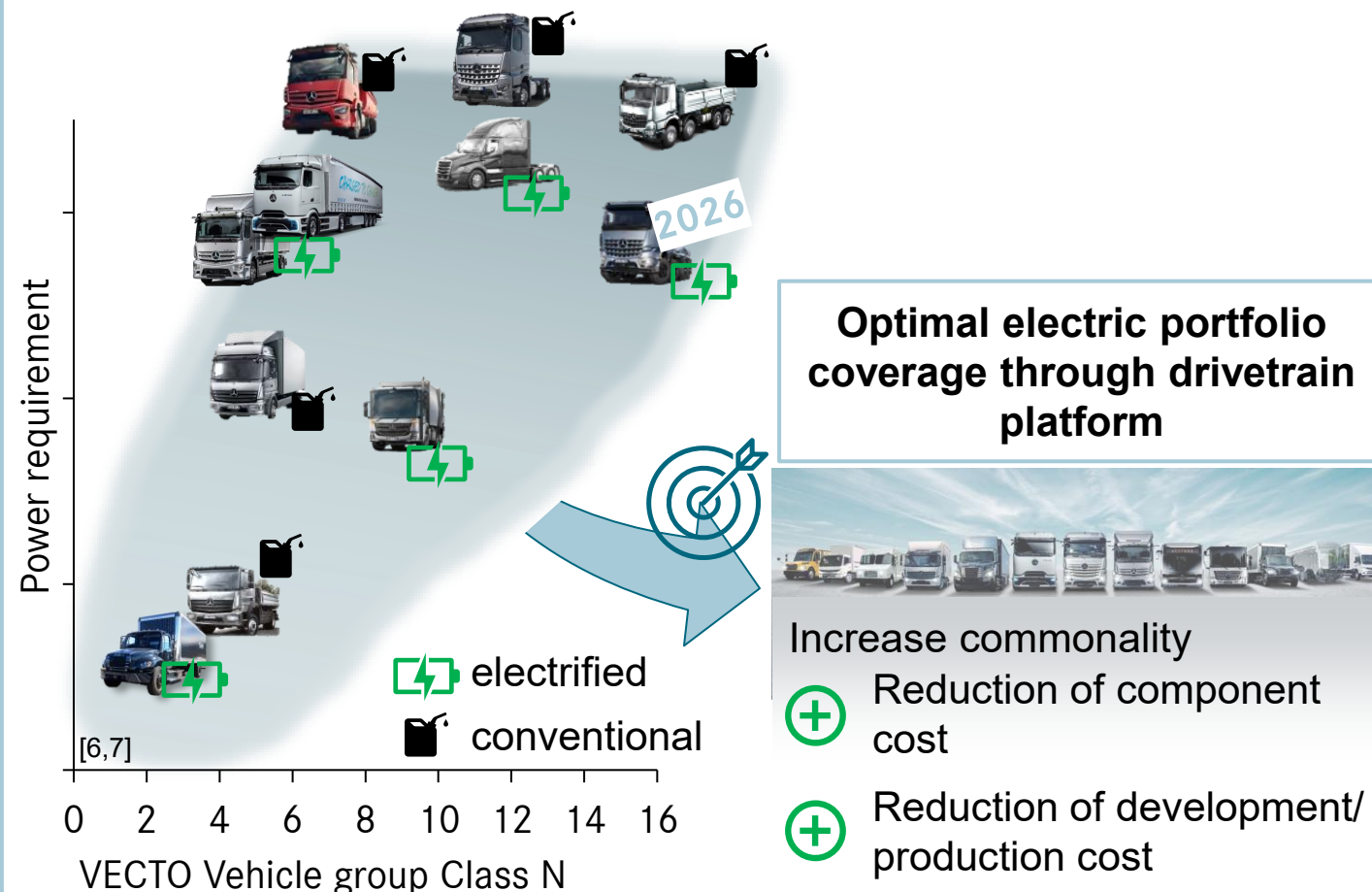
Background

CO₂-reductions for Heavy-Duty trucks effective from 2025 introduced 2019 (baseline 2019/20 emission levels)



[1]

Platform development



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Automated drivetrain platform design targeting the challenge of different vehicle use-cases in the truck industry

❗ **Challenge:** Different use-cases of vehicles → wide weight range → adaptive and scalable drivetrain approach

📋 **Exemplary dynamic (cycle) and static driving requirements**

Long-Haul (LH)			Distribution (DB)			Municipal (MC)			Construction (CS)		
 40t [3]			 35t [2]			 25t [4]			 60t [5]		
Priority 1			Priority 2			Priority 3			Priority 4		
Vecto LongHaul Cycle			Vecto Regional Delivery (RD) Cycle			Vecto Municipal Utility (MU) Cycle			Vecto Construction Cycle		
v [km/h]	a [m/s ²]	α [%]	v [km/h]	a [m/s ²]	α [%]	v [km/h]	a [m/s ²]	α [%]	v [km/h]	a [m/s ²]	α [%]
0	0.2	12	0	0.2	12	0	0.2	12	0	0.1	30



Solution: Automated drivetrain platform design



Portfolio Analysis

Priorities and performance requirements of portfolio vehicles



Modular Usage

Priority 1 eDrive serves as basis

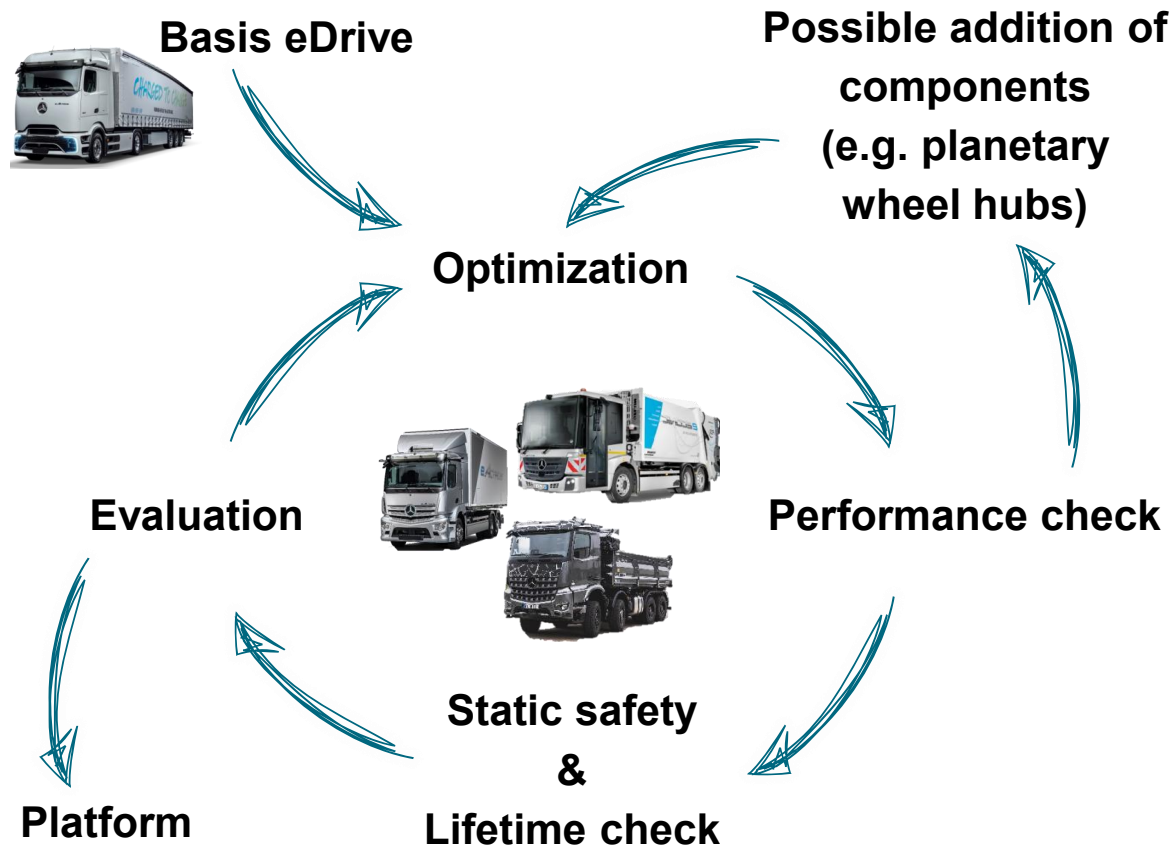


Component Optimization

Multi-objective optimization of drivetrain components

Platform optimization with topology variation, gear stage & final drive optimization, and possible additional planetary wheel hubs

Optimization Process



Optimization

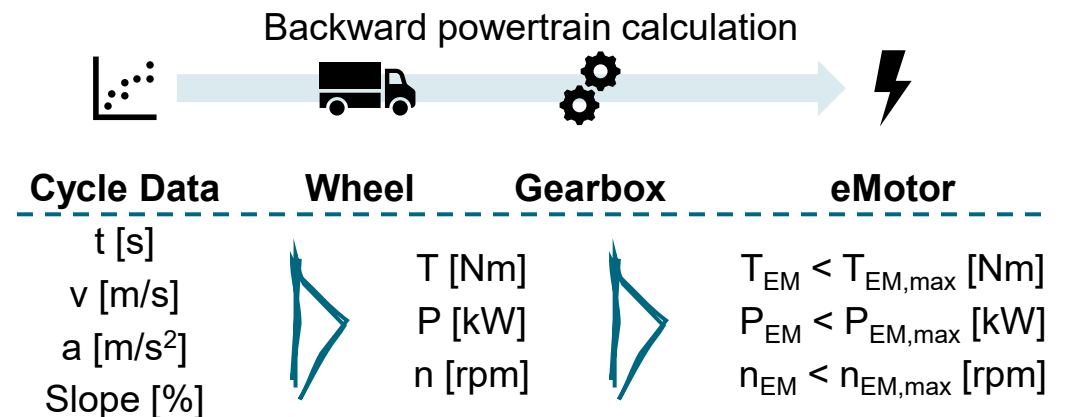
→ Genetic algorithm

Constraints

$$\begin{array}{lll}
 i_{\text{spg}} = [1.1 \ 4] & i_{\text{WH}} = [3 \ 5] & a_{\text{spg}} = \text{const.} \\
 i_{\text{plg}} = [3 \ 6] & w = [5 \ 100] \text{ mm} & p = [3 \ 6] \\
 i_{\text{FD}} = [2 \ 4.5] & m = [2 \ 8] \text{ mm} & z = [17 \ 200]
 \end{array}$$

i: gear ratio; m: gear module; a: shaft distance;
w: gear width; p: # of planets; z: # of teeth

Performance check

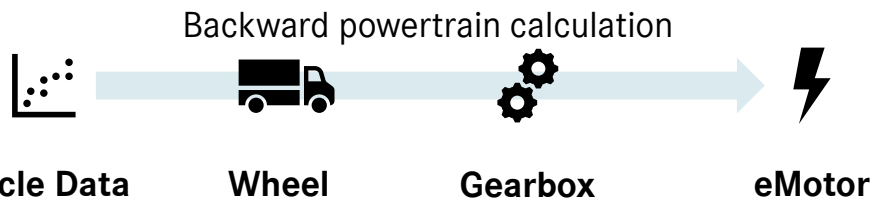


Multi-objective optimization of eDrive electrical energy demand and cost, including consideration of component share rate

General minimization problem

$$\min(E_{el} \cdot q_P, C \cdot q_C); \quad q_i: \text{respective weighting factors}$$

Electrical energy demand E_{el}



- E-Motor efficiency through power losses
- Gearbox efficiency for spur and planetary gears and final drives:
 - Load-dependent: constant efficiencies
 - Load-independent: rough speed-dependent churning losses

$$E_{el} = \sum_i^{LP} (P_{mot,mech} + P_{mot,loss}) \cdot w_i$$

w_i : time-based weighting factor or each LP

Cost C

- Component-specific generic models
 - E-Motor (C_{mot}) ~ torque & Material cost
 - Gearset (C_{gbx}) ~ mass ~ volume
- System
 - $C_{eDrive} = (\overrightarrow{C_{Mot}} \cdot \overrightarrow{S_F} + \overrightarrow{C_{gbx}} \cdot \overrightarrow{S_F}) \cdot ICM$
 - Scaling factor S_F (economy of scale)

$$S_F = \left(\frac{\text{new \# of parts}}{\text{old \# of parts}} \right)^{-0.1}$$
 - Indirect cost multiplier ICM (overhead cost)

$$ICM = f(\text{Complexity})$$
 - Share Rate SR

$$SR = \frac{\text{equal components to basis}}{\text{components in current eDrive}} \sim \text{gear modules}$$

of gear module ~ # of hobbing cutters

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Exemplary platform scenarios based on component variation and addition as 100% commonality is not feasible for construction truck

Platform Scenarios and Weightings

Scenarios

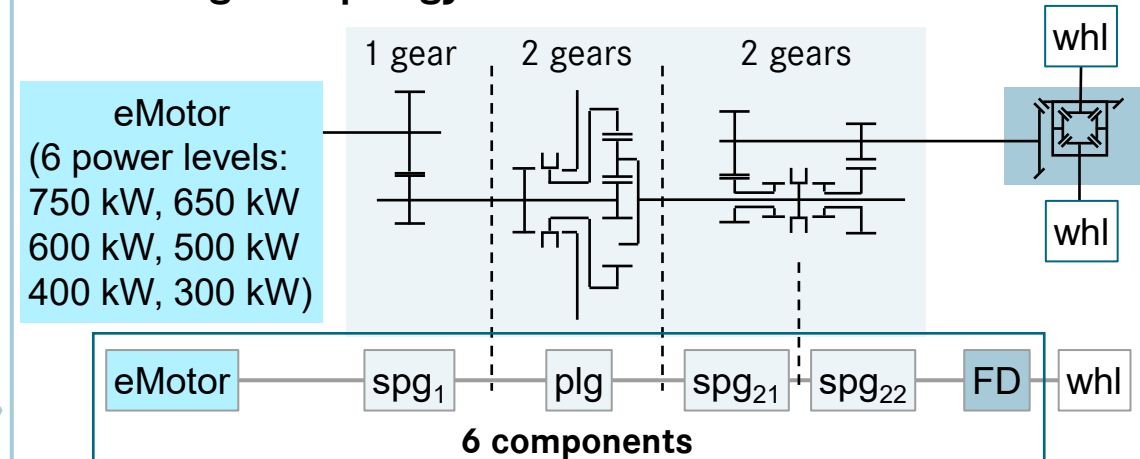
- commonality**
- 100% commonality across all vehicles
 - Platform optimization considering:
 - Topology variation
 - Transmission and final drive (FD) optimization
 - Possible addition of planetary wheel hubs (WH)

Weightings

- | | |
|--------------|---------------|
| Long-Haul | → Efficiency |
| Distribution | → Efficiency |
| Municipal | → Cost |
| Construction | → Performance |

Exemplary Platform Basis

Basis 4-gear topology



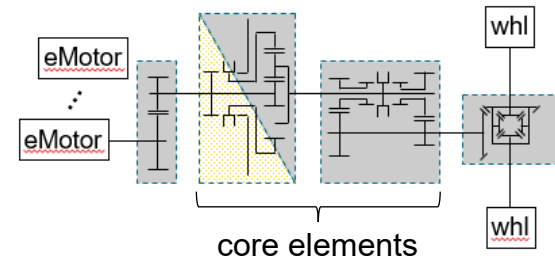
1st Scenario: 100% commonality (SR = 1)

Priority

Truck	eMotors	Gearbox	Final Drive
LH (Basis)	Basis eMotors	Basis Gearbox	Basis FD
DB	=	=	=
MC	=	=	=
Construction	Not feasible	Not feasible	Not feasible

DB: Platform optimization with topology variation and gear stage & final drive optimization

Topology



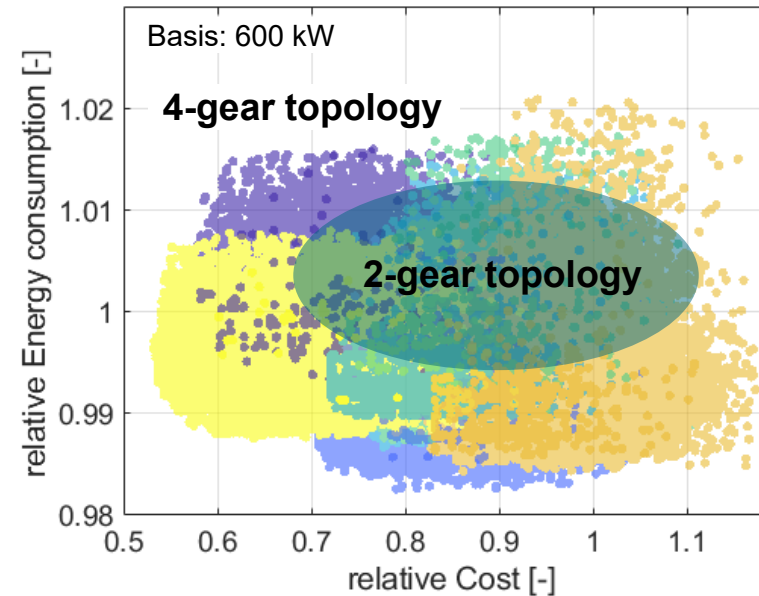
6 components

pos. omission	Used or not
varied	Optimized
core elements	Width optimization

Key findings

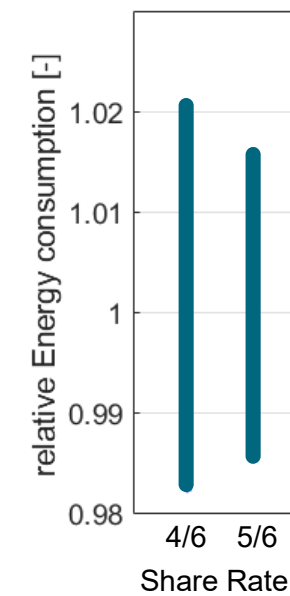
- **2- and 4-Gear topologies** possible
- **4-Gear topologies** show **less relative cost**, due to possibility of less powerful eMotor (2-gear topology requires min. 500 kW)
- **4-Gear topologies** show **less energy consumption**
- Sharing of up to 5 out of 6 components (SR = 1 not optimal)
- Lower share rate (~ same gear modules) may result in less energy consumption, due to better efficiency optimization; reduced cost, based on less powerful eMotors possible

DB Truck

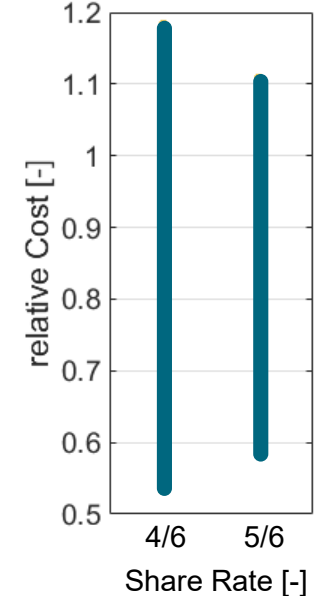


4-gear topology*

Energy consumption vs. share rate



Cost vs. share rate



*2-gear topology shows same trends

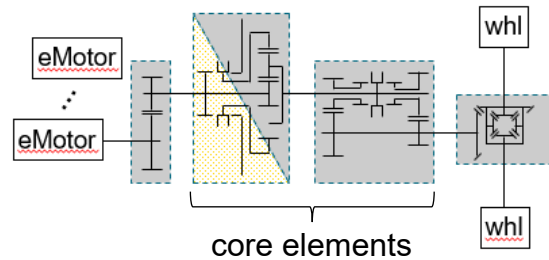
eMotors



Area of 2-Gear topologies

MC: Platform optimization with topology variation and gear stage & final drive optimization

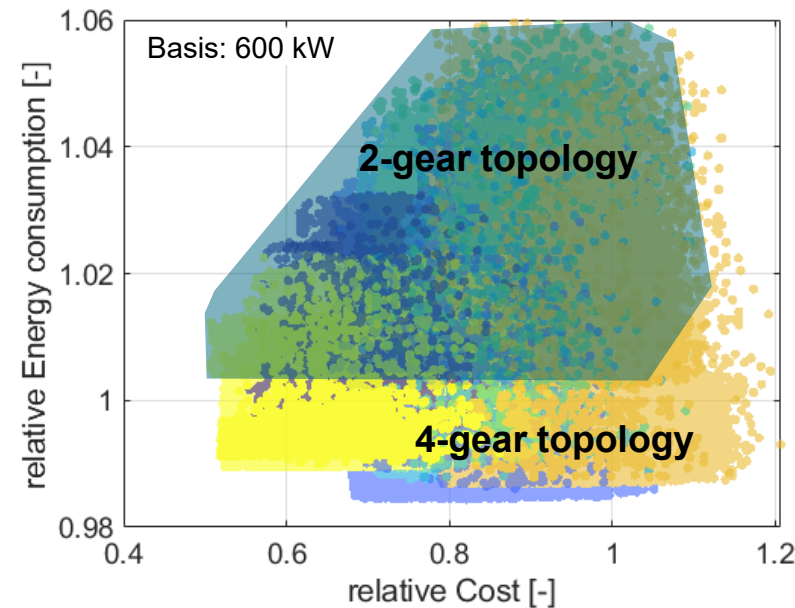
Topology



6 components

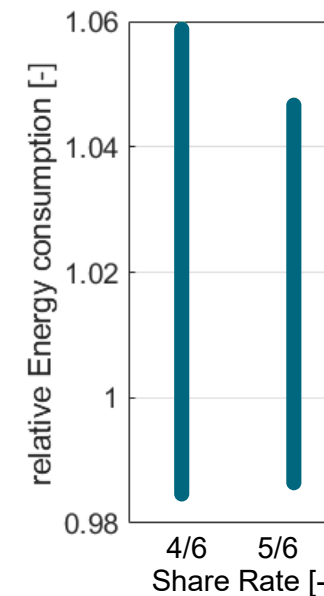
pos. omission	Used or not
varied	Optimized
core elements	Width optimization

MC Truck

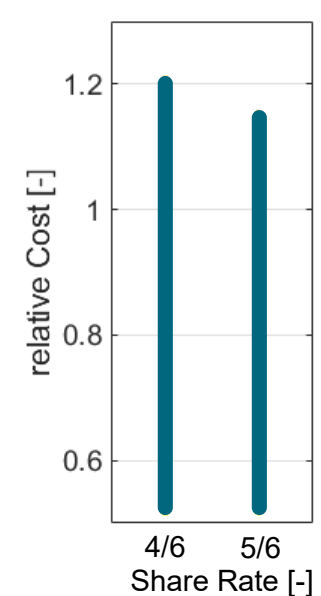


4-gear topology*

Energy consumption vs. share rate



Cost vs. share rate



Key findings

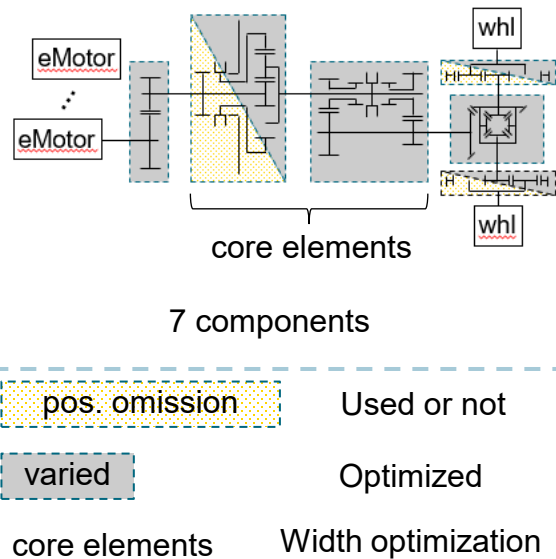
- **2- and 4-Gear topologies** possible
- **2-Gear topologies** show **less relative cost**, due to missing planetary gear stage
- **4-Gear topologies** show **less energy consumption**
- Sharing of up to 5 out of 6 components possible (SR = 1 not optimal)
- Less share rate (~ same gear modules) may result in slightly reduced energy consumption, due to better efficiency optimization; cost might be slightly increased

*2-gear topology shows same trends eMotors



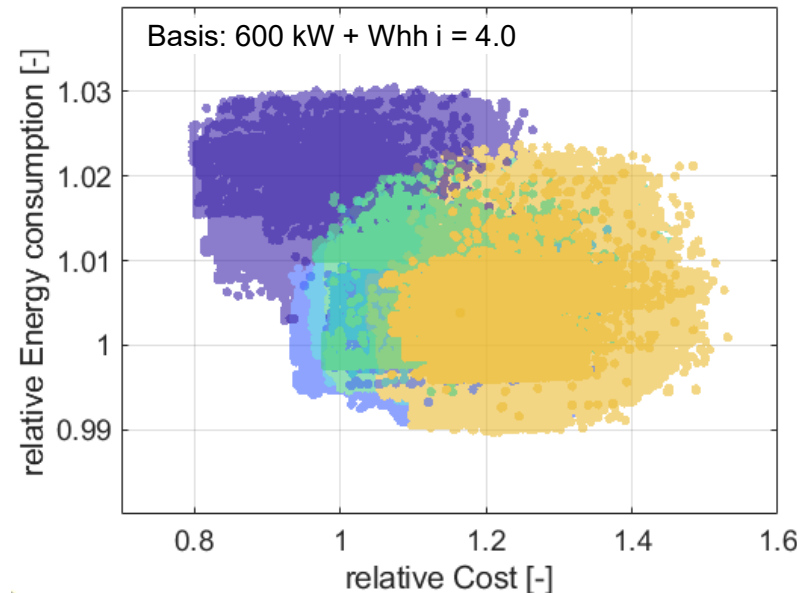
CS: Platform optimization with topology variation, gear stage & final drive optimization, and additional wheel hubs to increase wheel torque

Topology



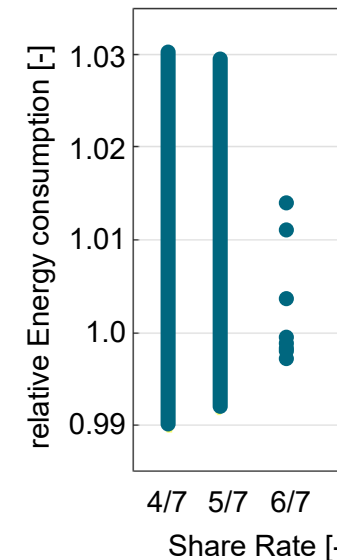
CS Truck

4-gear topology

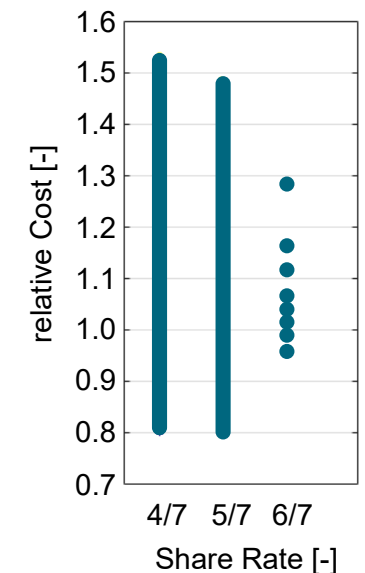


4-gear topology

Energy consumption vs. share rate



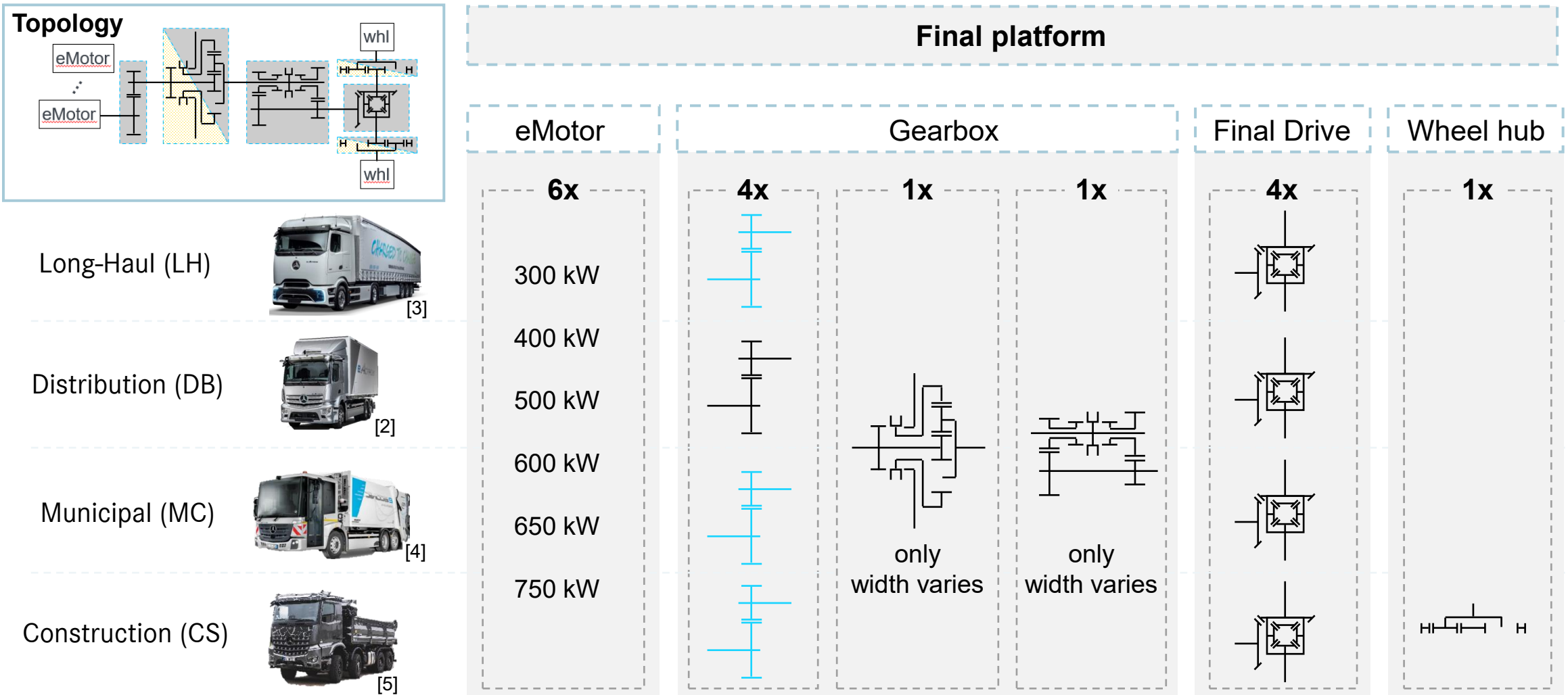
Cost vs. share rate



Key findings

- **Only 4-Gear topologies** possible
- eMotors from 400 kW to 750 kW possible
- The **higher** the **eMotor power** the **more cost intensive**
- Sharing of up to 6 out of 7 components possible
- Less share rate (~ same gear modules) may result in less energy consumption, due to better efficiency optimization; reduced cost, based on less powerful eMotors possible

Final platform consist of six eMotors, four single spur gear stages, one planetary gear stage, one shiftable spur gear stage, four FDs, and one planetary wheel hub



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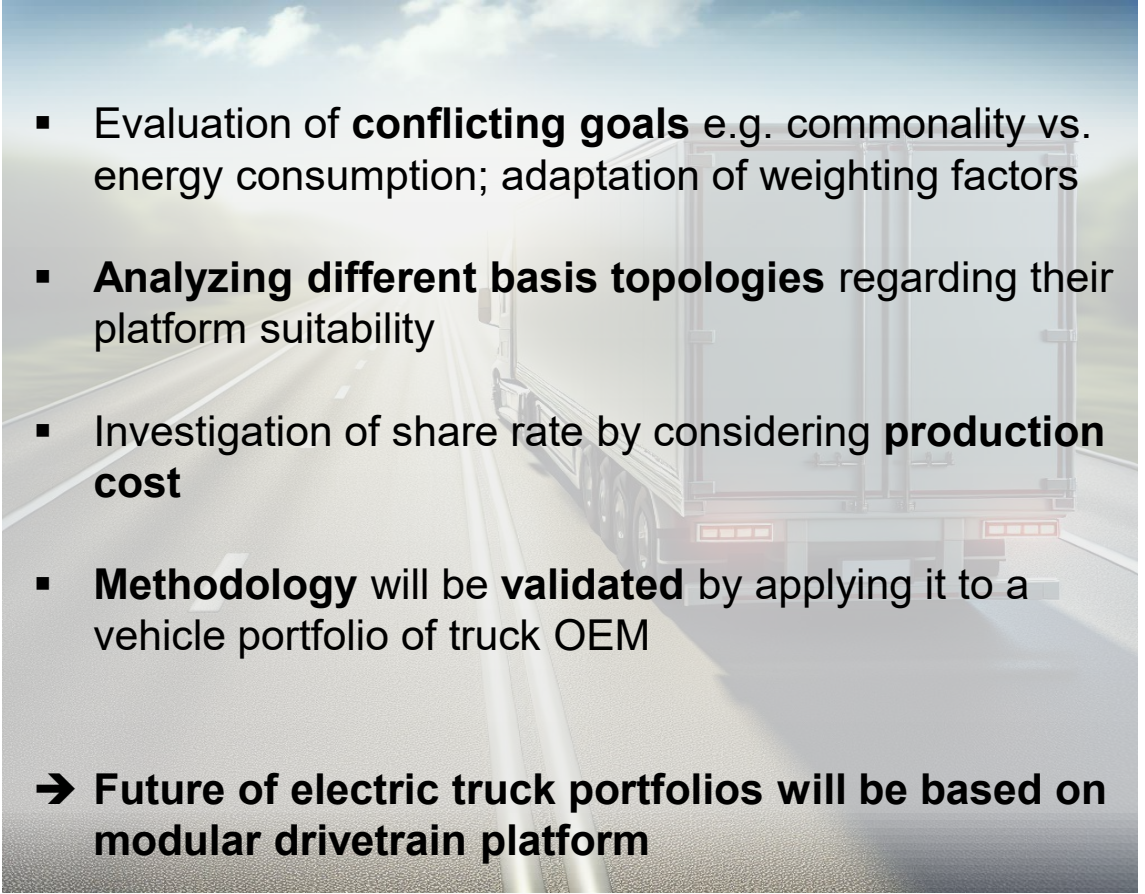
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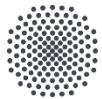
Commonality in drivetrain components for portfolio electrification is possible

Summary

- **Different use-cases** of trucks
- Less production volume than passenger car industry
→ **tailored development and production is cost-intensive**
- **New platform approach for optimal portfolio coverage**
 - Automatic platform design based on **portfolio analysis, modular principle, and component variation**
 - Increase of **commonality** possible but **influencing energy consumption and performance**
 - High share rates may reduce cost depending on material and manufacturing prices

Outlook

- 
- Evaluation of **conflicting goals** e.g. commonality vs. energy consumption; adaptation of weighting factors
 - **Analyzing different basis topologies** regarding their platform suitability
 - Investigation of share rate by considering **production cost**
 - **Methodology** will be **validated** by applying it to a vehicle portfolio of truck OEM
 - **Future of electric truck portfolios will be based on modular drivetrain platform**



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Thank you for your attention!



Philip Hätscher

Daimler Truck AG

R&D TechTeam eDrive System
Fasanenweg 10, 70771 Leinfelden-Echterdingen

www.daimlertruck.com

philip.haetscher@daimlertruck.com

University of Stuttgart

Institute of Automotive Engineering Stuttgart (IFS)
Pfaffenwaldring 12, 70569 Stuttgart

www.ifs.uni-stuttgart.de

philip.haetscher@ifs.uni-stuttgart.de

References



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- [2] B. Wunderlich, VDI Wissensforum: Development of a Heavy Duty eAxle for Worldwide Application within Daimler Truck Portfolio (2023)
- [3] C. Krajewski, cti symposium: Daimler Truck on the Way to CO2 Neutrality (Berlin, 2024)
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