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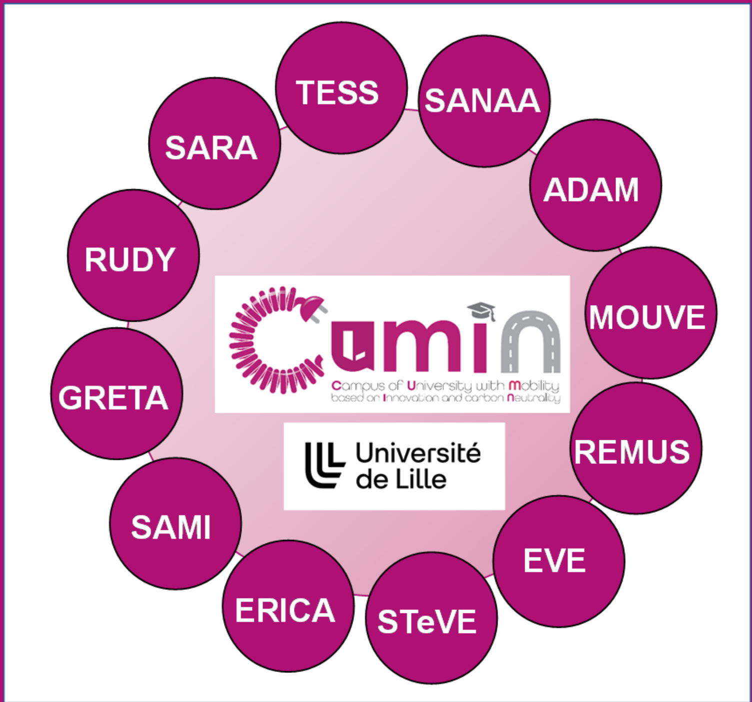

CUMIN - STeVE

Scalability of powertrain for electrified vehicles and application to en e-bus

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A. Bouscayrol[a], P. Sergeant[b] & F. Verbelen[b]

[1] University of Lille, L2EP, France

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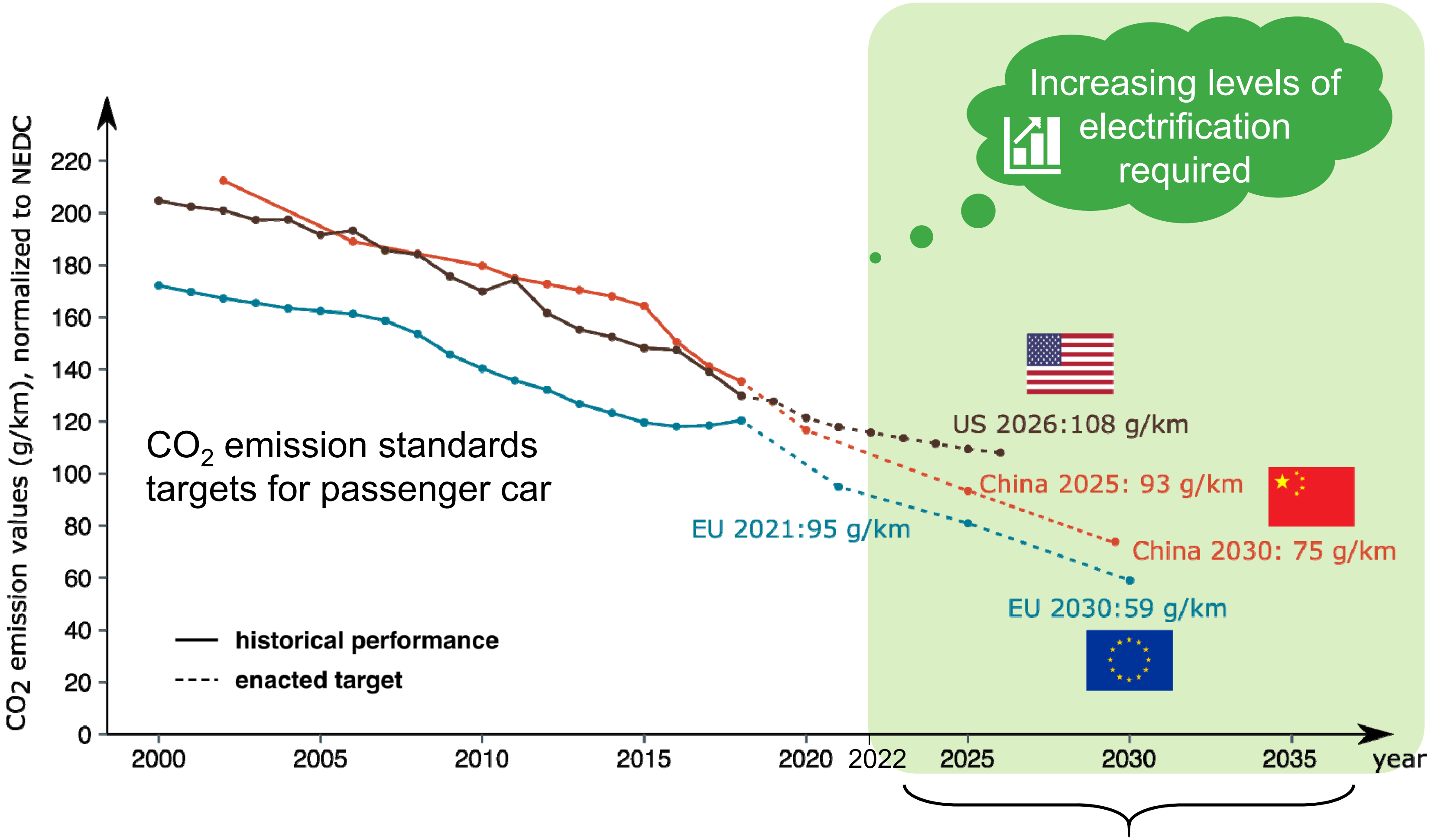
Outline

1. Project context, objective & framework

2. Brief overview on the scaling methods

3. Case study: electric bus

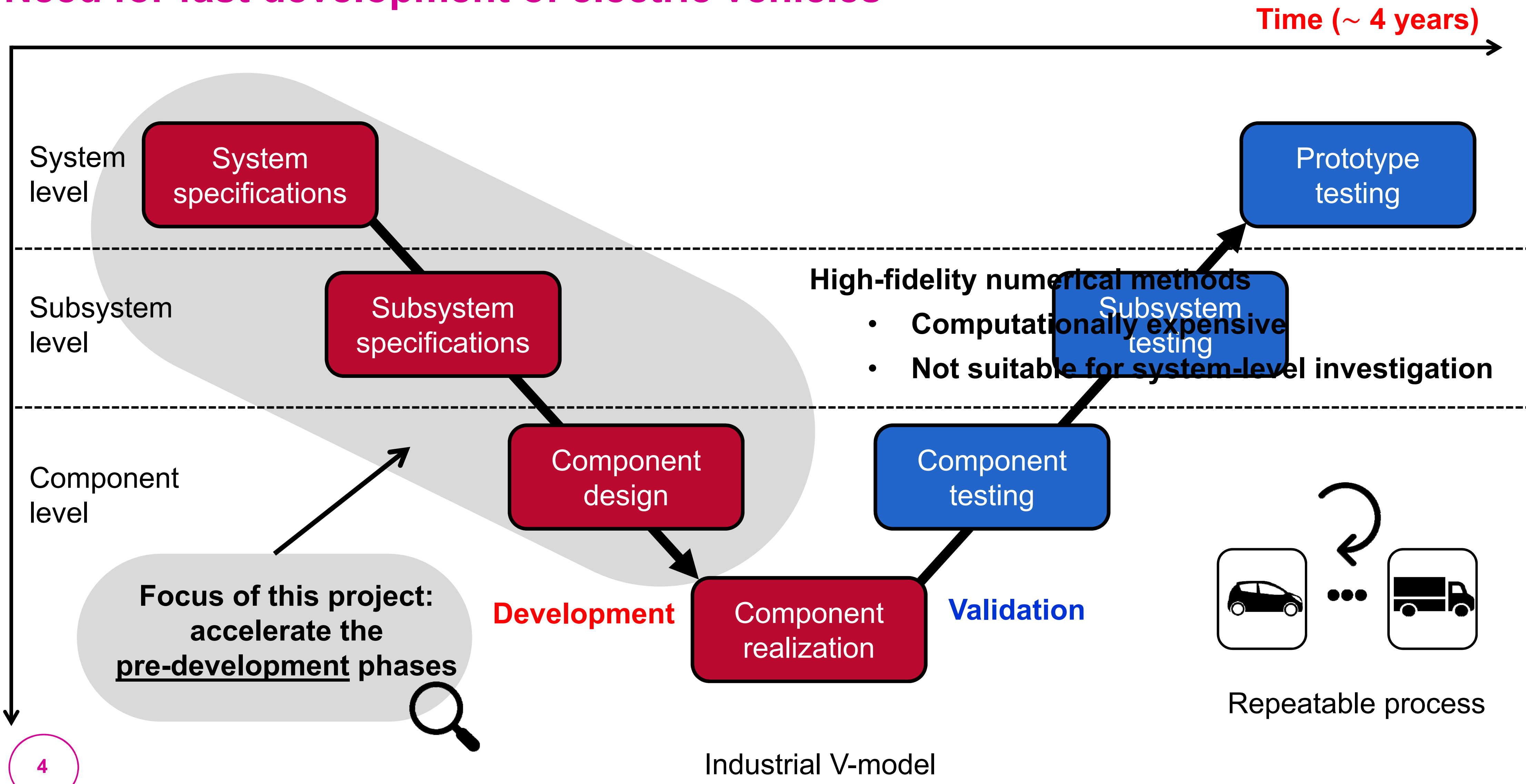
Fast moving CO_2 regulation pathway to 2030



Regulations tightening further with a short time frame

Ref: International Council on Clean Transportation ICCT

Need for fast development of electric vehicles

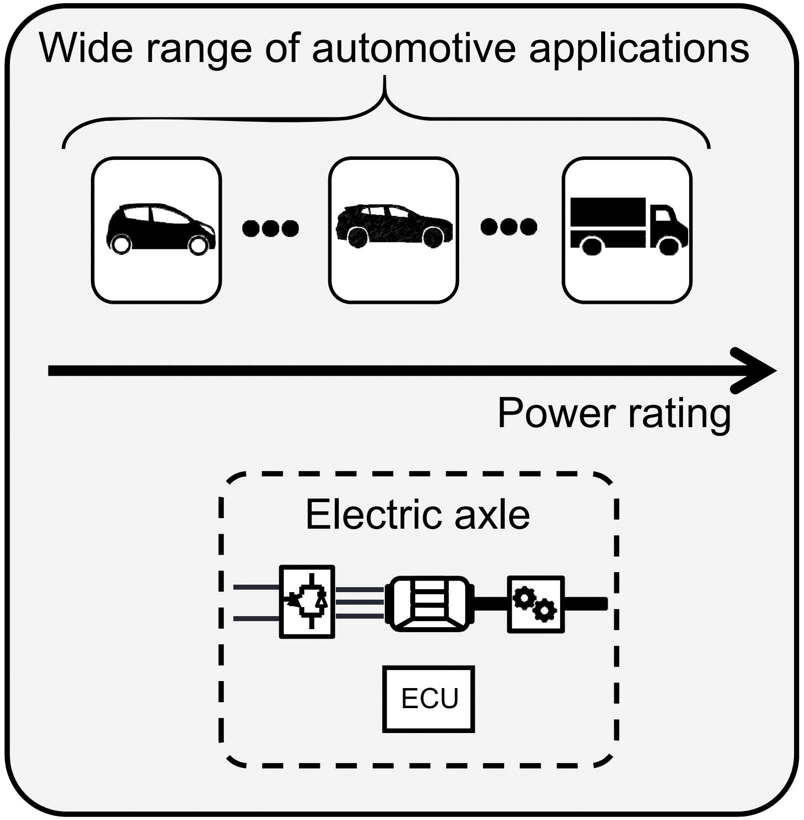


Scalability: a solution?

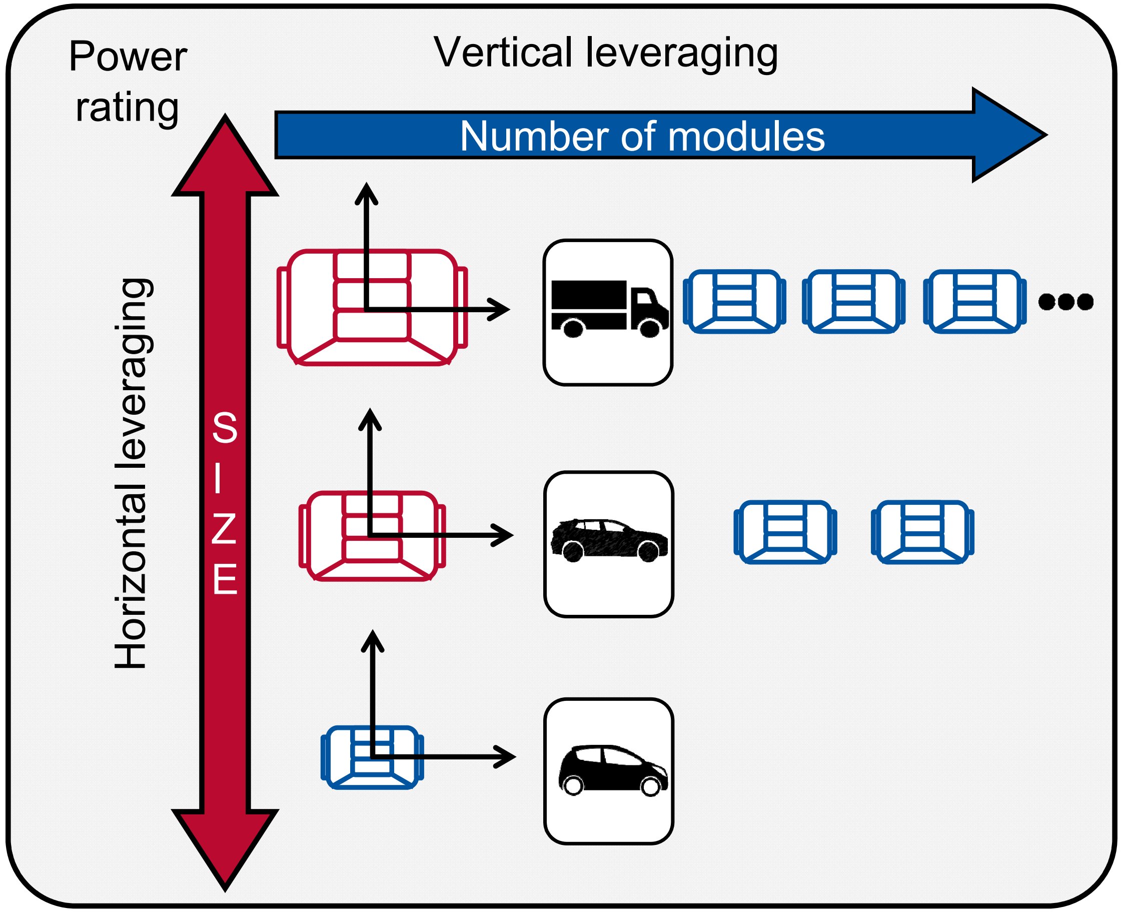
Electric motors product series

- Geometric changes in size of a reference object
- Predicting the performances of a new design based on the data from an existing one
- Reduce the computational effort

Scalability & automotive applications



- Same components, but diverse requirements…
- Need for methodologies supporting powertrains scalability



Scaling-leveraging strategies
for powertrain components
(electric motor as an illustrative case)

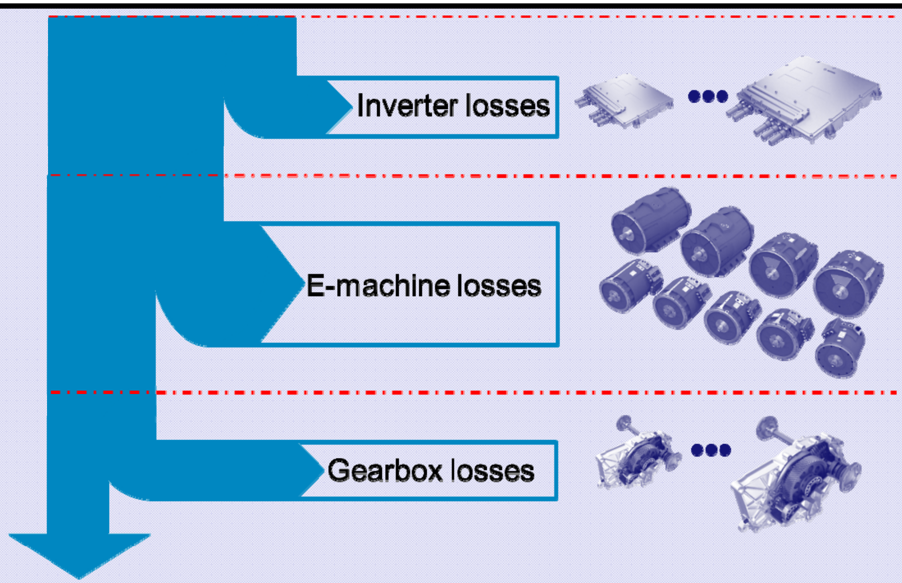
Project objective & challenges

Objective:

Develop a scaling method for electric axle systems (inverter-electric motor-gearbox) for system-level investigations

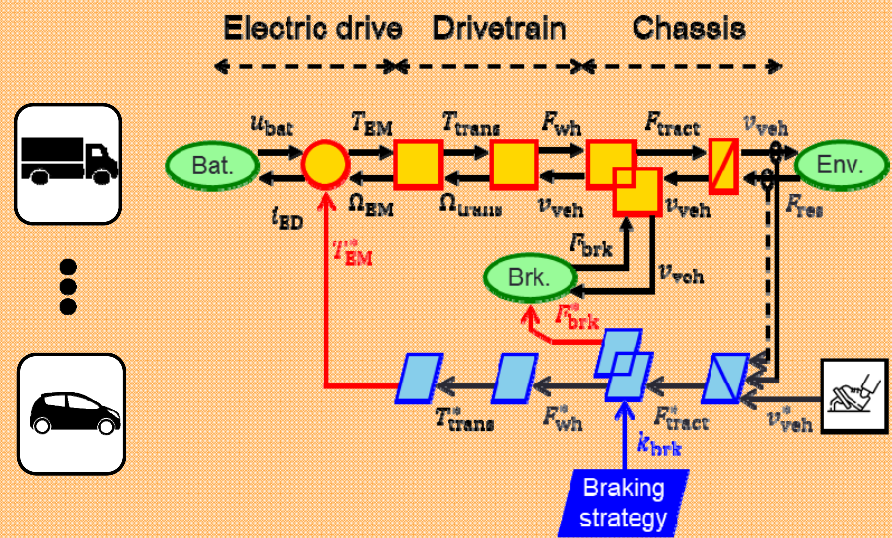
Challenges:

Component-level



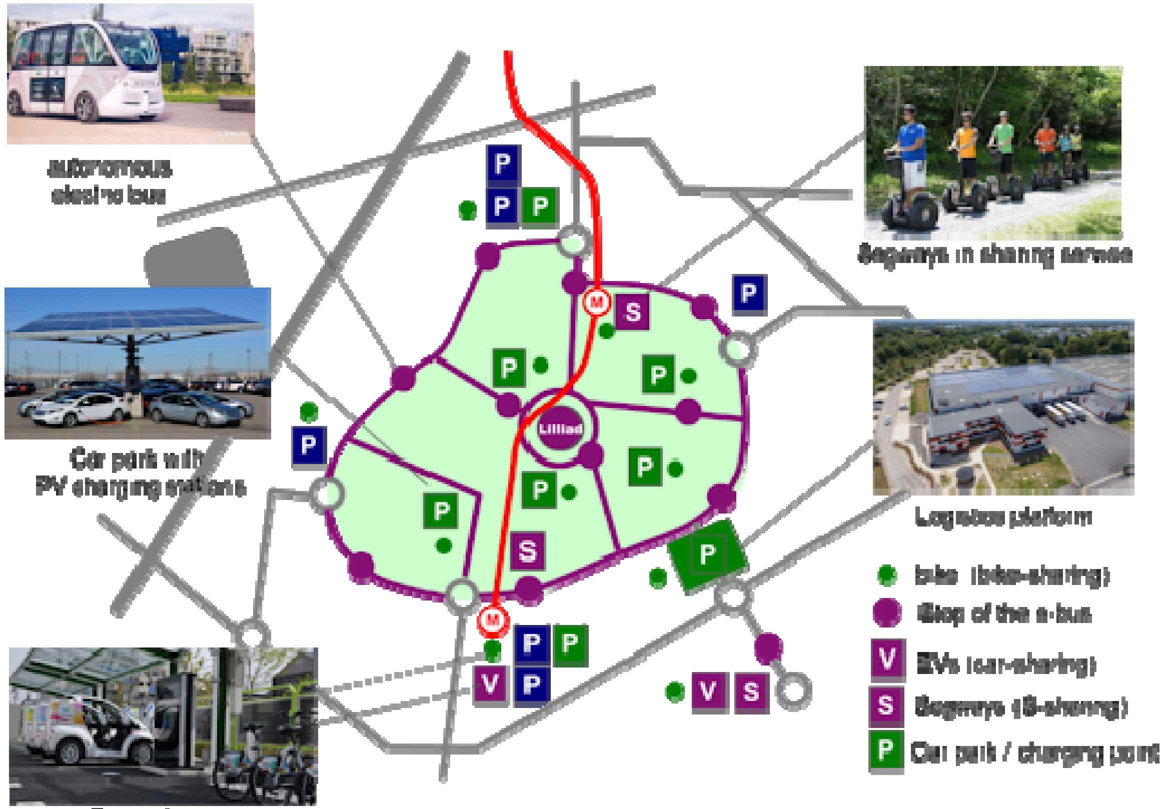
- Deriving scaling laws of the parameters and losses

System-level



- Ease of implementation at system-level
- Simulation of different automotive applications

Within the framework of CUMIN



Possible eco-campus scheme

Fast energy consumption assessment of different vehicles (light vehicles, buses, trucks) for a “green” campus

Project framework: a joint Franco-Belgian PhD

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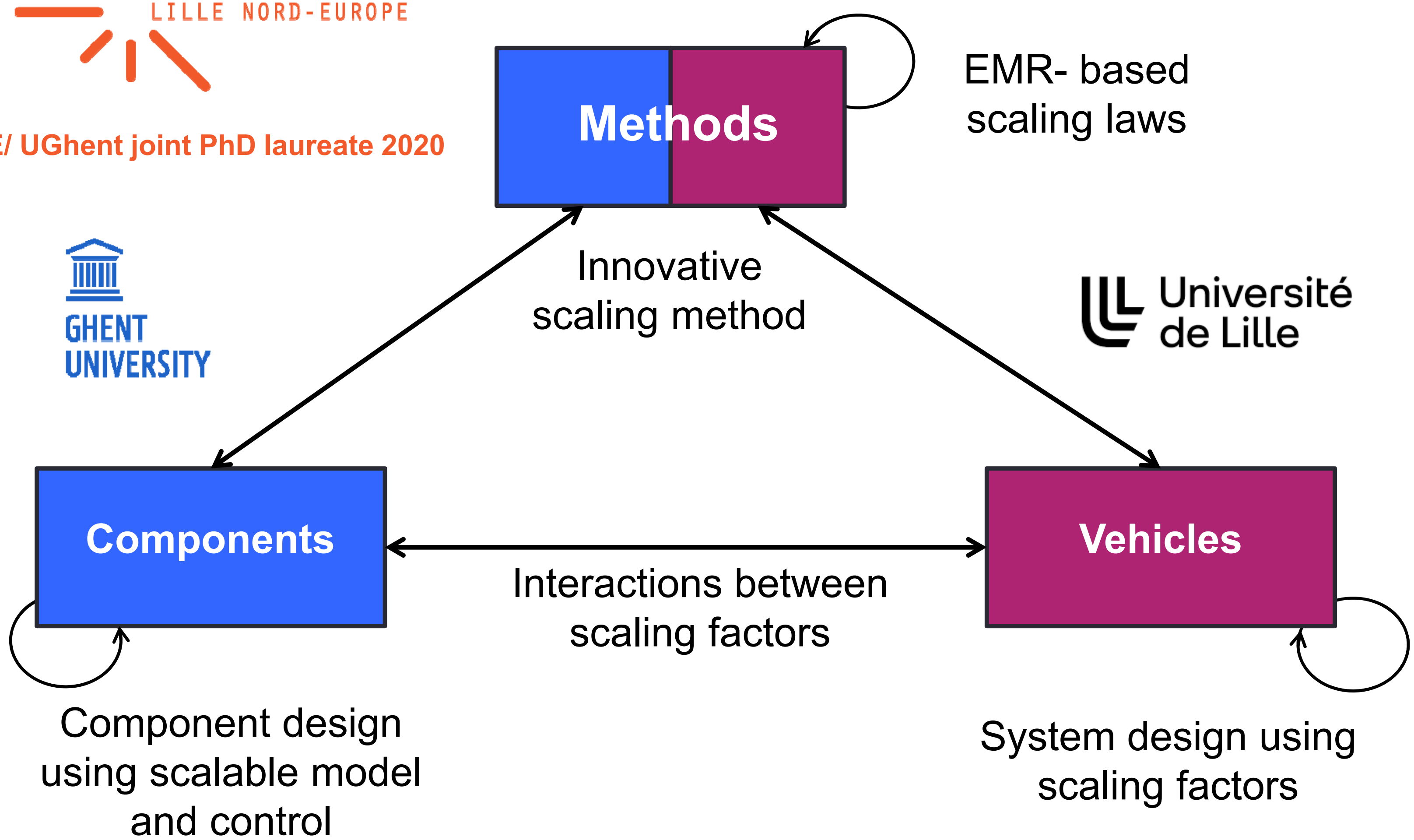
I-SITE/ UGhent joint PhD laureate 2020

GHENT UNIVERSITY

Université de Lille



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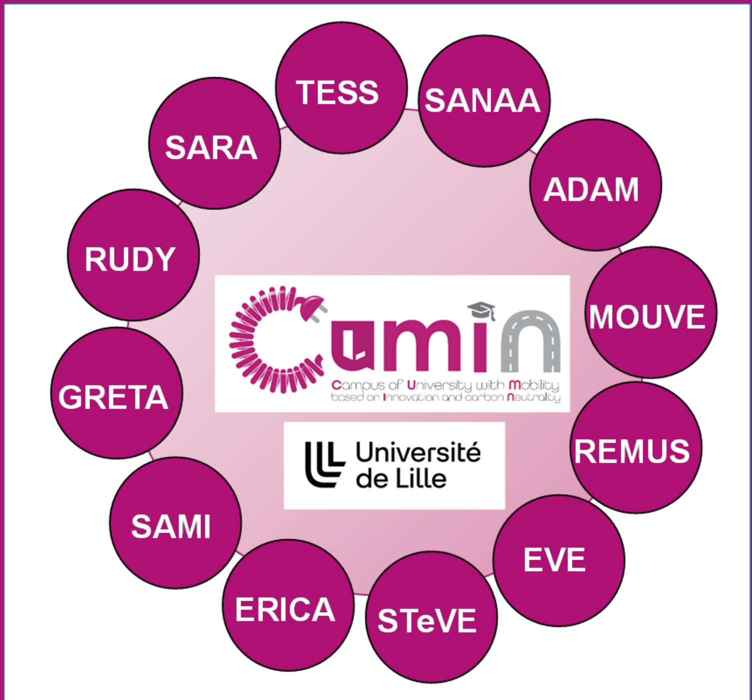

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Brief overview on the scaling methods

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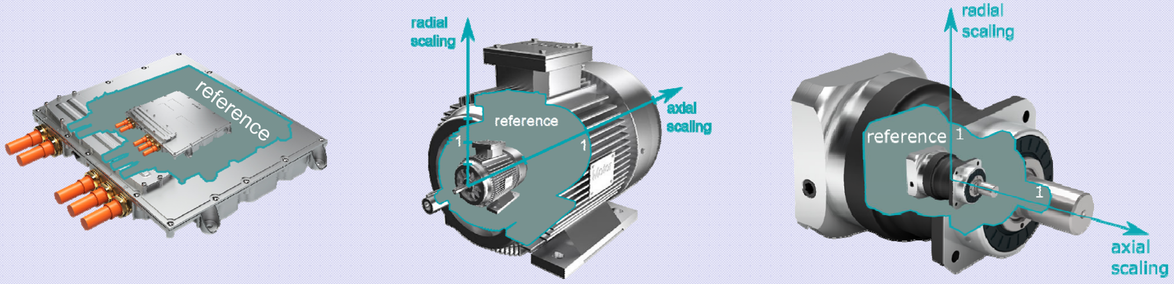
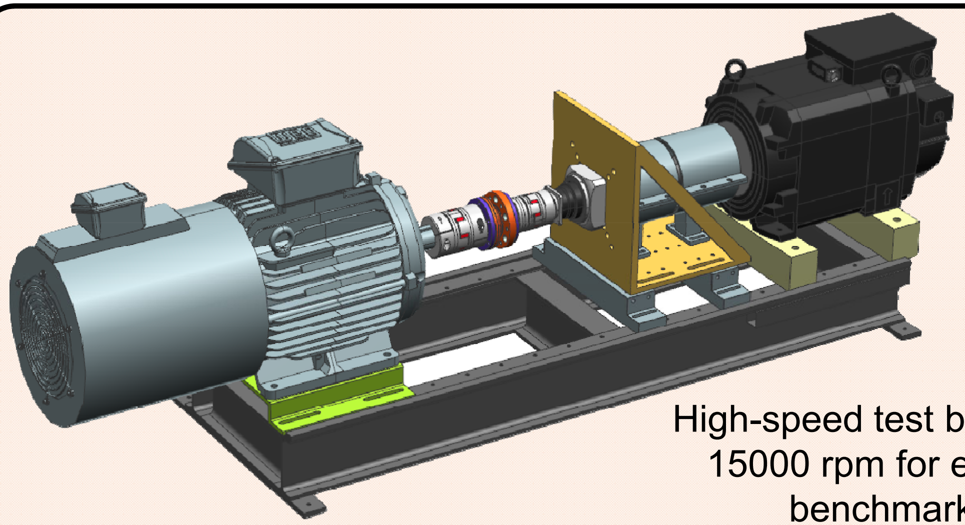
Component-level: scaling laws applied to components

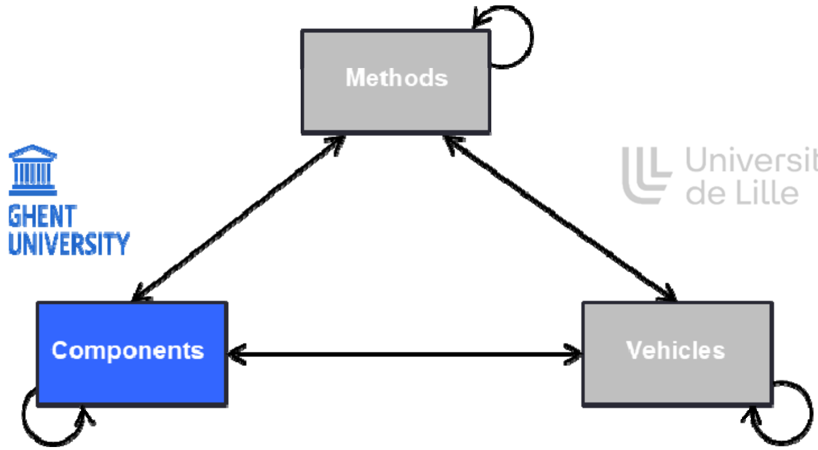
Scaled inverters | Scaled electrical motors | Scaled gearboxes



Analytical derivation

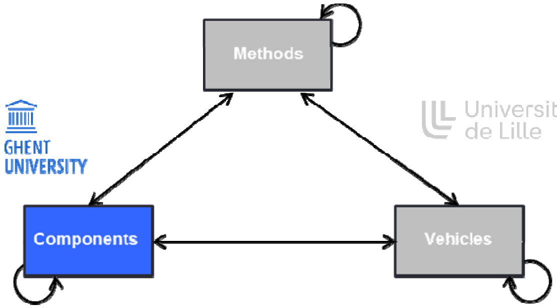


High-speed test bench up to 15000 rpm for efficiency benchmarking

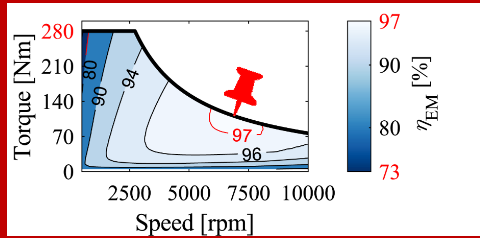


Experimental campaign to validate the theoretical scaling laws using a series product family

Component-level: scaling laws applied to components



Reference design of an electric motor

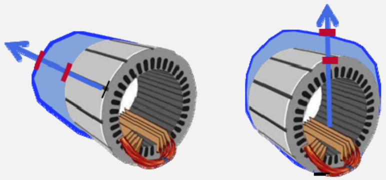


Efficiency map

Power scaling factor K_P ex. 1.3

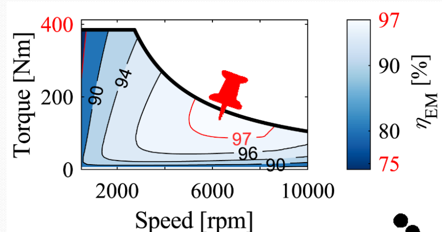
Loss component distribution

- **Geometric scaling**: Axial scaling K_A and Radial scaling K_R

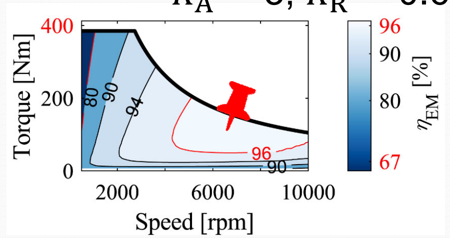


- **Losses mapping**: $P'_{\text{losses}} = f(K_P, K_A, K_R)\, P^0_{\text{losses}}$

$K_A = 1.5,\ K_R = 0.96$

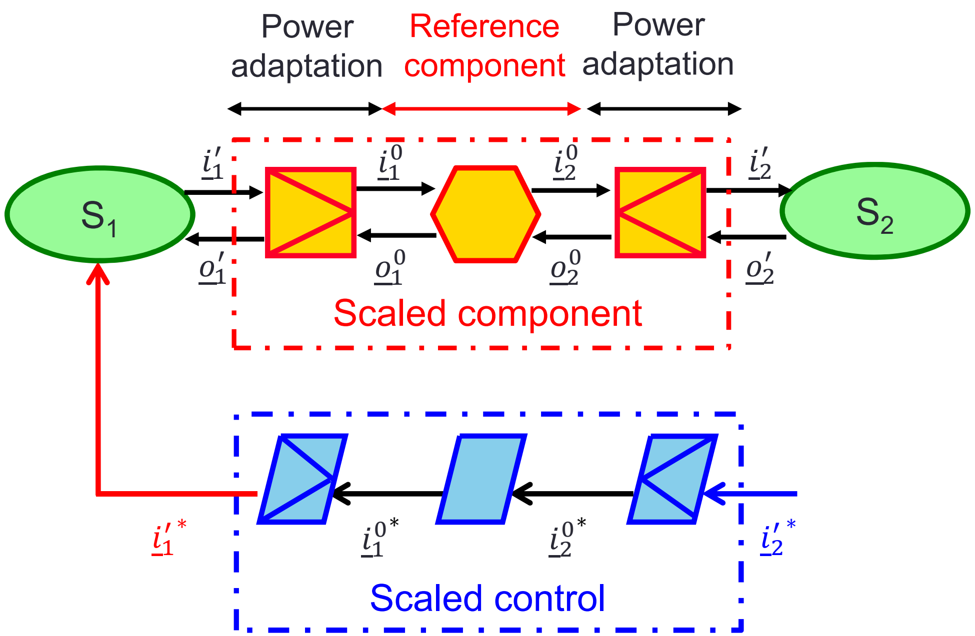


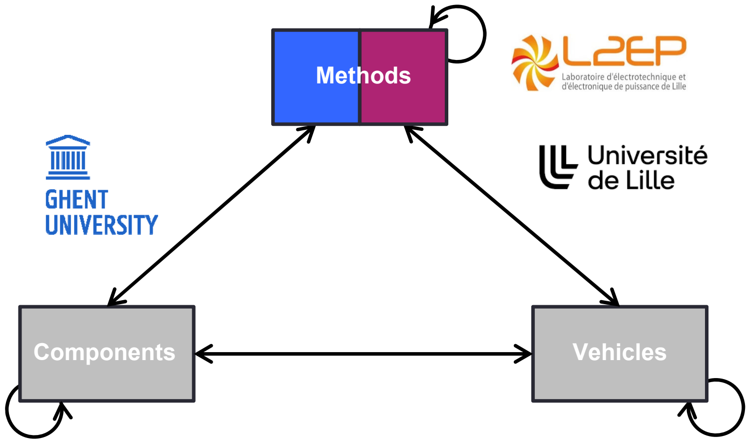
$K_A = 3,\ K_R = 0.67$



Different options

New model organization to facilate the incorporation of scalability in simulations





Objective: organize the models and control of scaled components in a unified way

➔ Easy reuse of models and control for different tasks

➔ Speed up the pre-design time

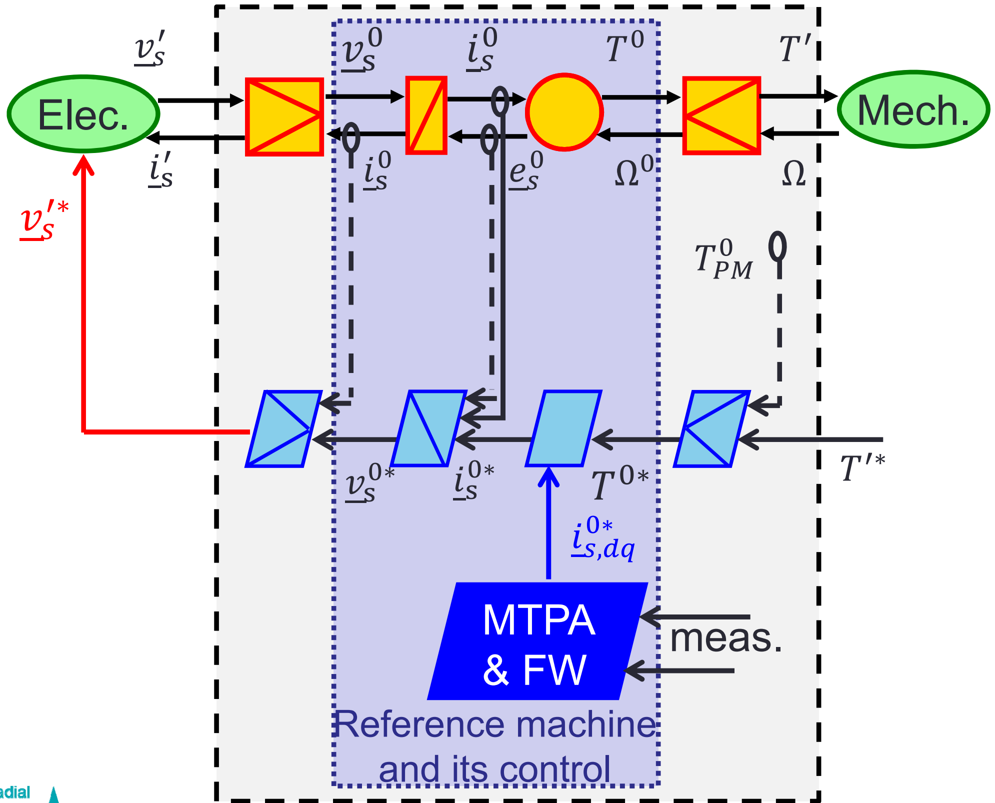
Challenge: derive equations for power adaptation elements

New model organization of a scaled motor using EMR formalism

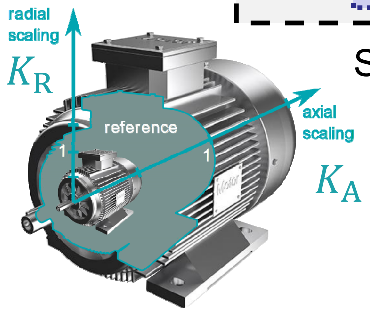
$$\begin{cases} \underline{v}_s^0 = \dfrac{\underline{v}_s'}{K_A K_R} - \Delta_R \underline{i}_s^0 \\ \underline{i}_s' = K_R \underline{i}_s^0 \end{cases}$$

Electric power adaptation

$$\underline{v}_{s,\mathrm{dq}}'^{*} = K_A K_R \left(\underline{v}_s^{0*} + \Delta_R \underline{i}_s^{0*} \right)$$



Scaled machine and its scalable control

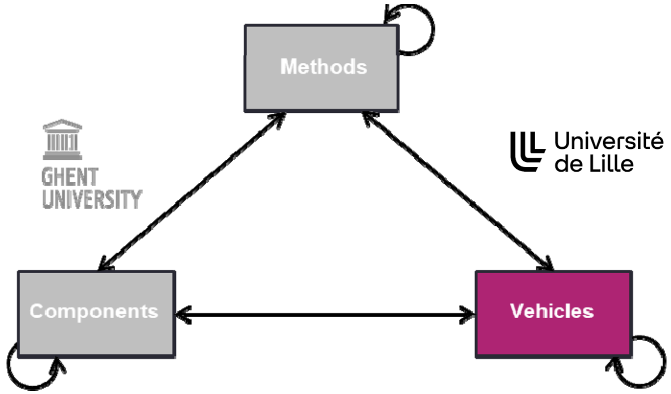


$$\begin{cases} T' = K_A K_R^2 T^0 - (K_R^2 - 1) T_{PM}^0 \\ \Omega = \Omega^0 \end{cases}$$

Mechanical power adaptation

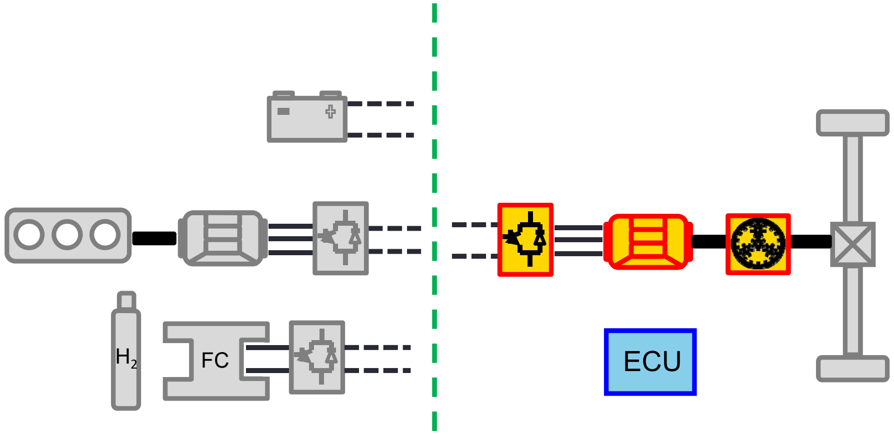
$$T^{0*} = \frac{T'^{*}}{K_A K_R^2} + \left(K_R^2 - 1\right) T_{\mathrm{PM}}^0$$

System-level: scaling laws applied to vehicles



❖ A common electrical powertrain for different types of vehicles:

- Battery electric vehicle
- Hybrid electric vehicle
- Fuel cell electric vehicle



❖ Testing of the effectiveness of the methodology on real case vehicles

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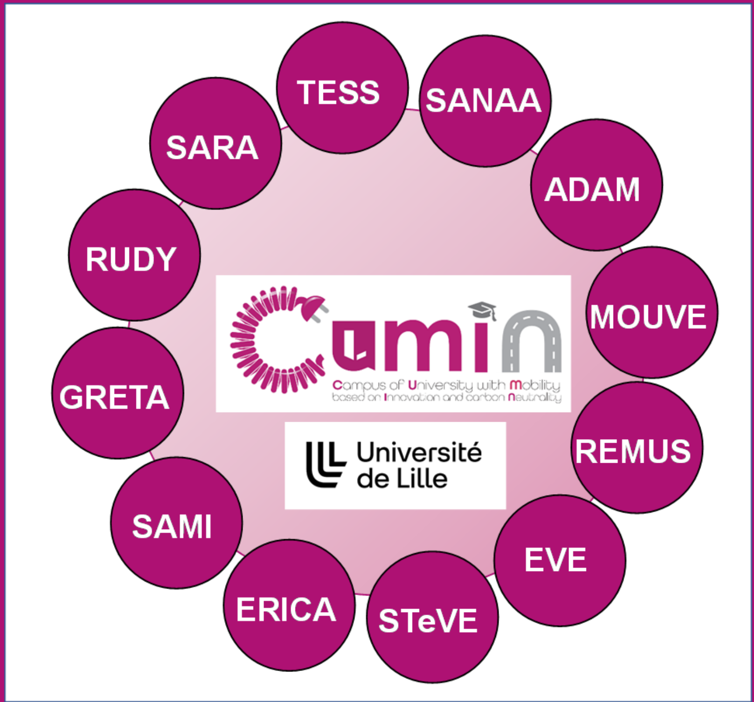

Case study: electric bus

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Scalability of electric drives for an electric bus

STeVE

Scaling methods

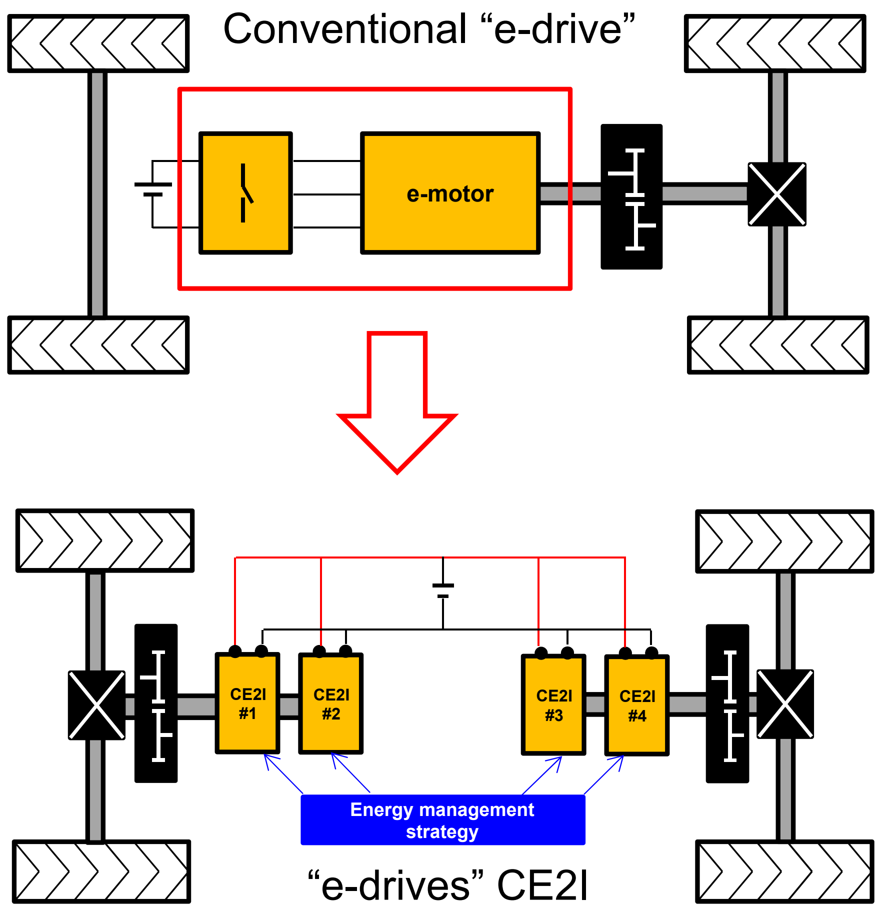
Efficient components and automotive applications

ALTAS interurban mini bus
(5800kg / 20 seats / e-drive 160 kW / Li-Ion NMC Bat. 115 kWh)
https://www.atlasautobus.com

E-drive CE2I (40 kW):

- 2 in the front axle
- 2 in the rear axle
- Intelligent energy mangement

Interests?



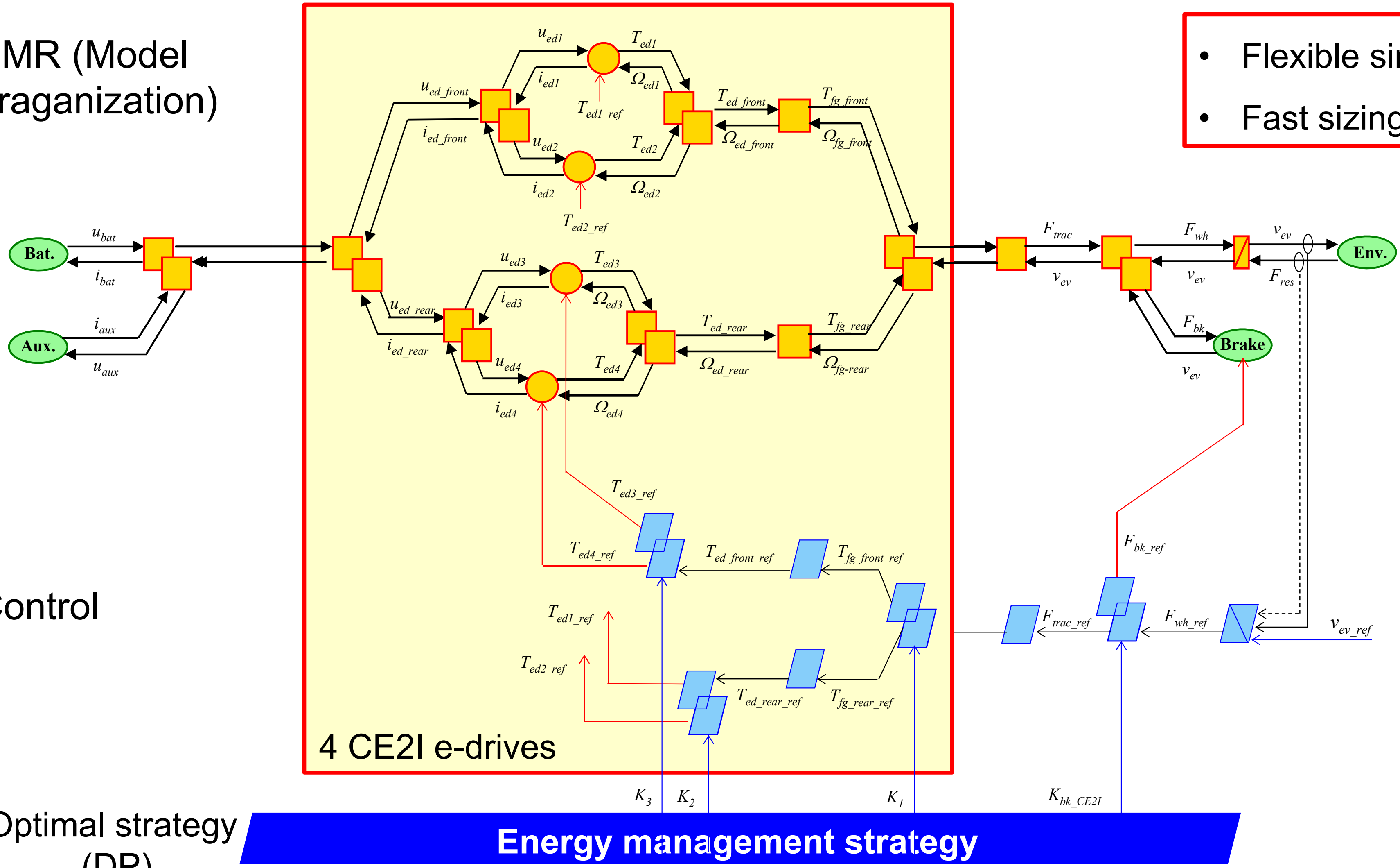
Based on the work conducted by K. Li *et al* within CE2I project

Virtual development of the multi-drives based electric bus

EMR (Model oraganization)

Control

Optimal strategy (DP)



- Flexible simulation tool
- Fast sizing of the e-drive

Comparison of energy consumption

- Braking strategy: 60% in the front axle and 40% in the rear axle (stability)

	Consumption (kWh/100km)		
Driving cycles	New York	London	Denver
Standard e-drive	77.0	43.8	66.1
4 CE2I e-drive	58.4	32.0	48.3
Consumption gain	**25.2 %**	**26.9 %**	**27.0 %**

Energetic gains despite a weight increase of 30 kg:

1) Regenerative braking
2) E-drive distribution

} Modultarity

3) Efficiency improvement —— Intelligent energy mangement

Conclusion

- Scalability
  - Rapidly generate and assess different preliminary designs using scaling laws
  - Ease of implementation at system-level simulations
  - Contribution to reduce the time of pre-design phases
- Results:
  - 1% to 27% gain compared to conventional electric drives
  - Potential of fault tolerance (modularity)
- Perspectives:
  - Extension of the application case to CUMIN vehicles

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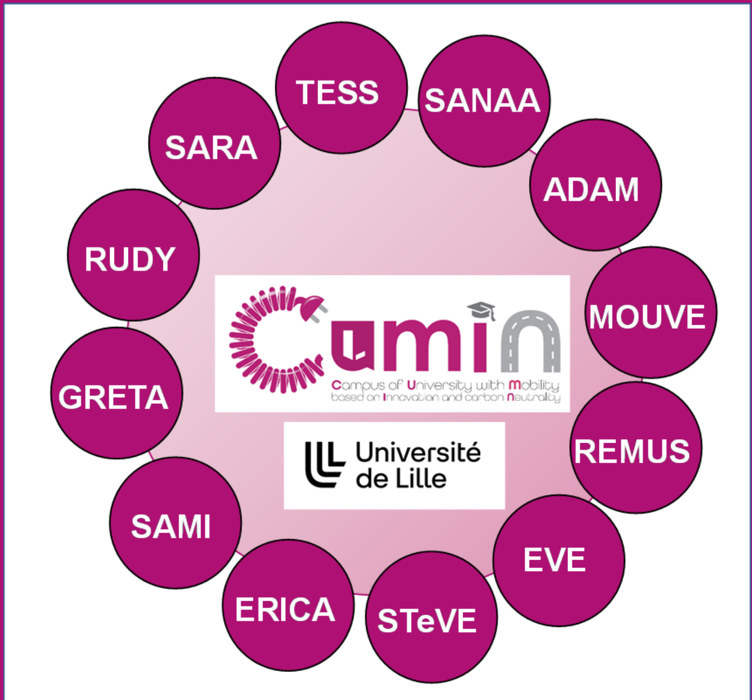

CUMIN programme

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an exciting living lab
towards eco-cities!