Concurrent Powertrain Design for a Family of Electric Vehicles

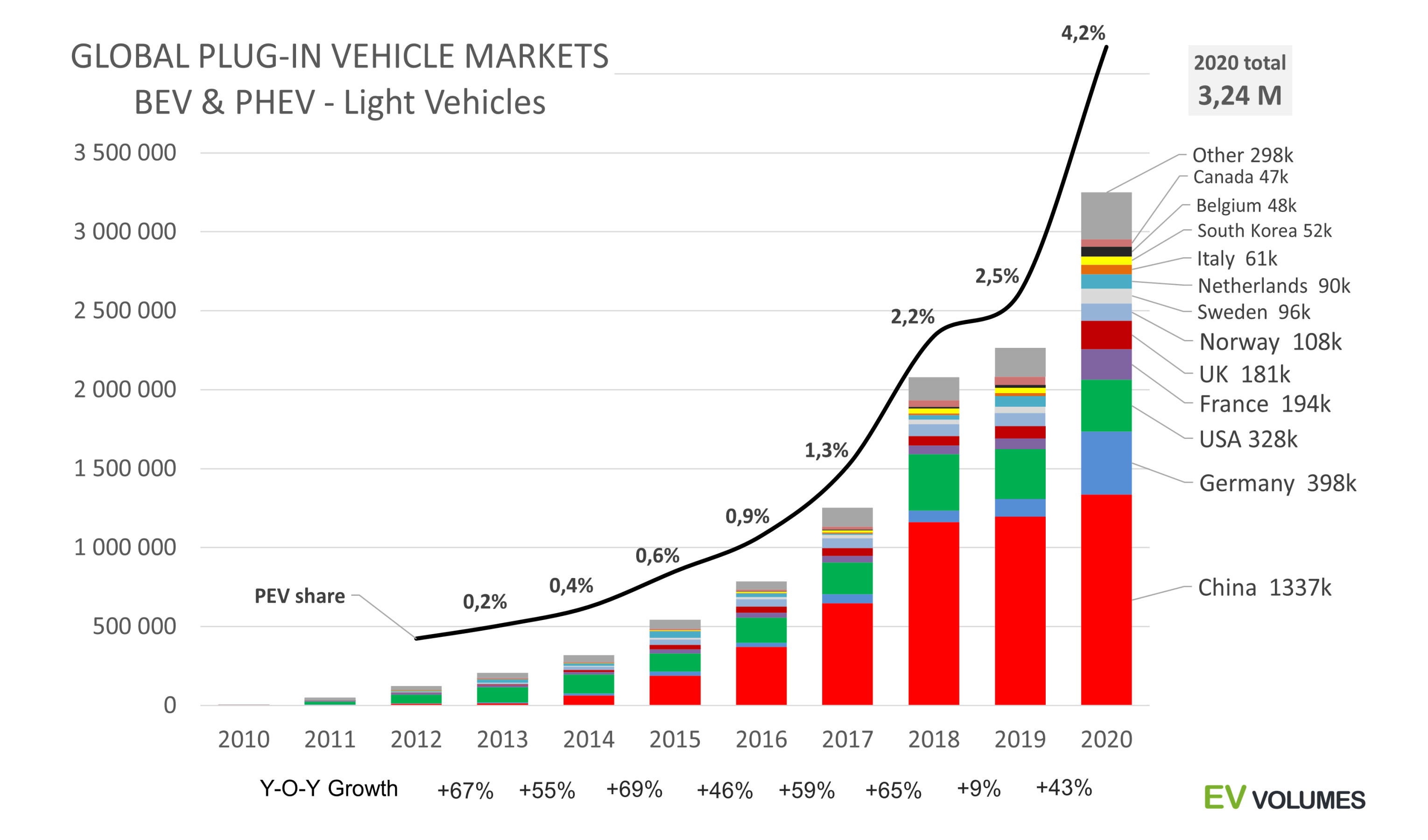
MAURIZIO CLEMENTE, PHD STUDENT

Eindhoven University of Technology

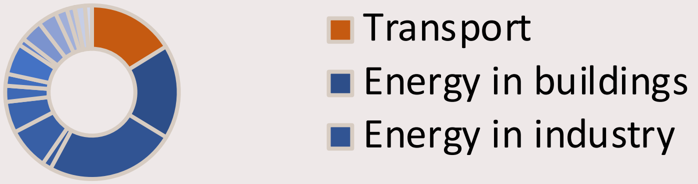
EVS35 International Electric Vehicle Symposium and Exhibition

NWO NEON research EVS35 OSL2022 TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Electric Mobility



Share of global GHG emissions (%) per sector in 2021



- Growing market
- EVs not common as we need

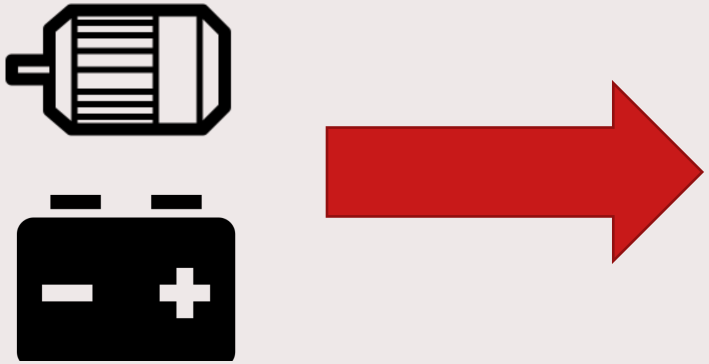
EVs have the potential to **cut emissions**

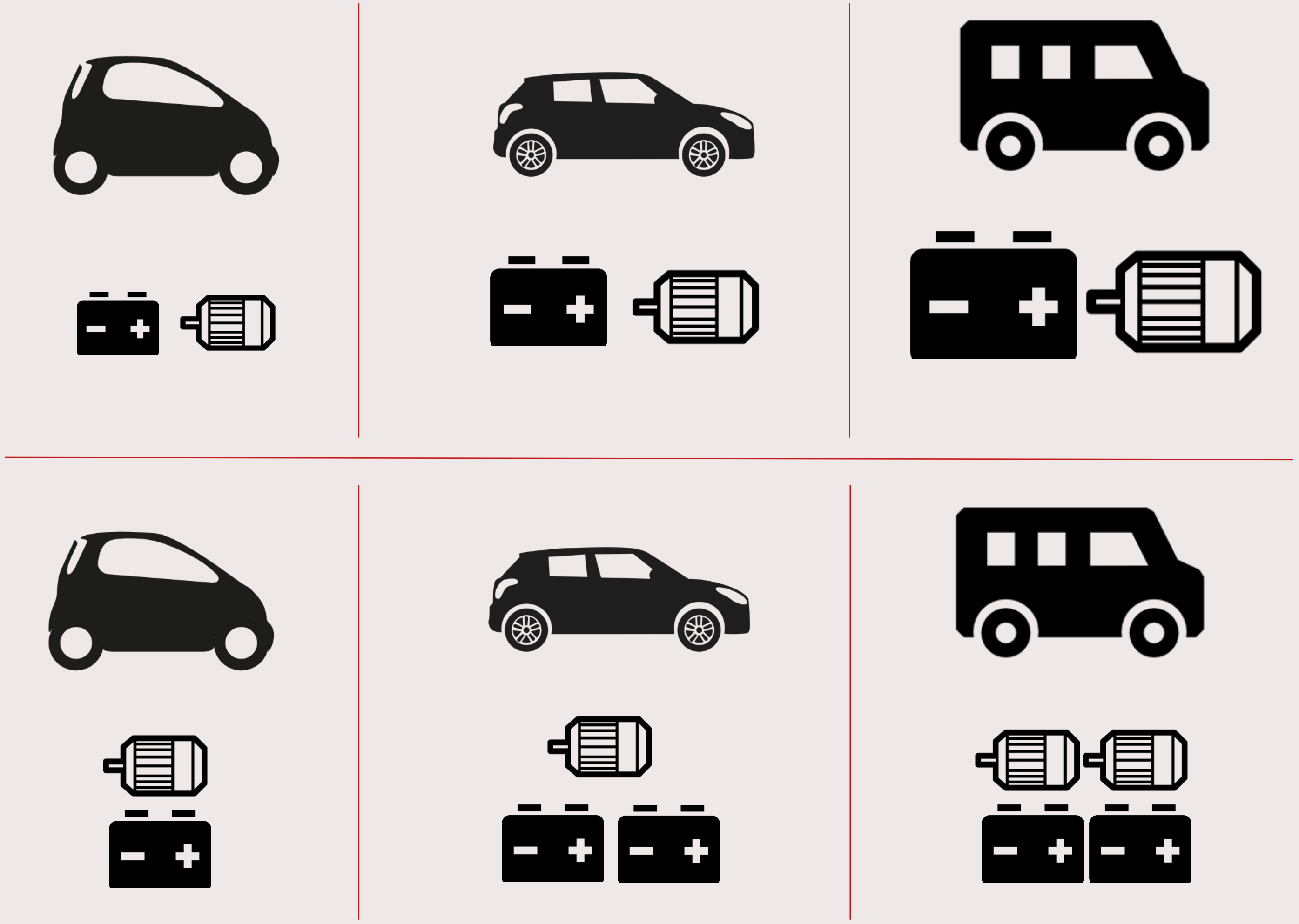
WHAT: Reduce **vehicles price…**

…while keeping consumption low

WHY: allow **more people** to access electrical mobility

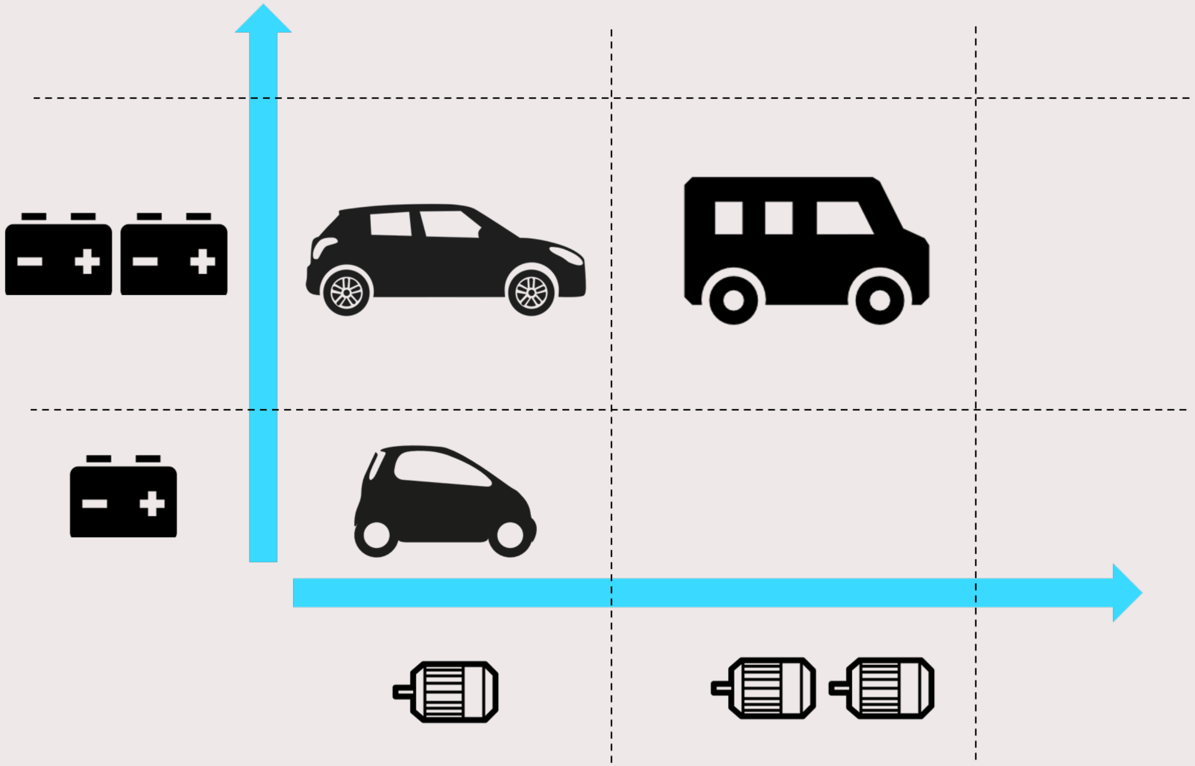
HOW: using product-family strategies such as **standardization** and **modularization**



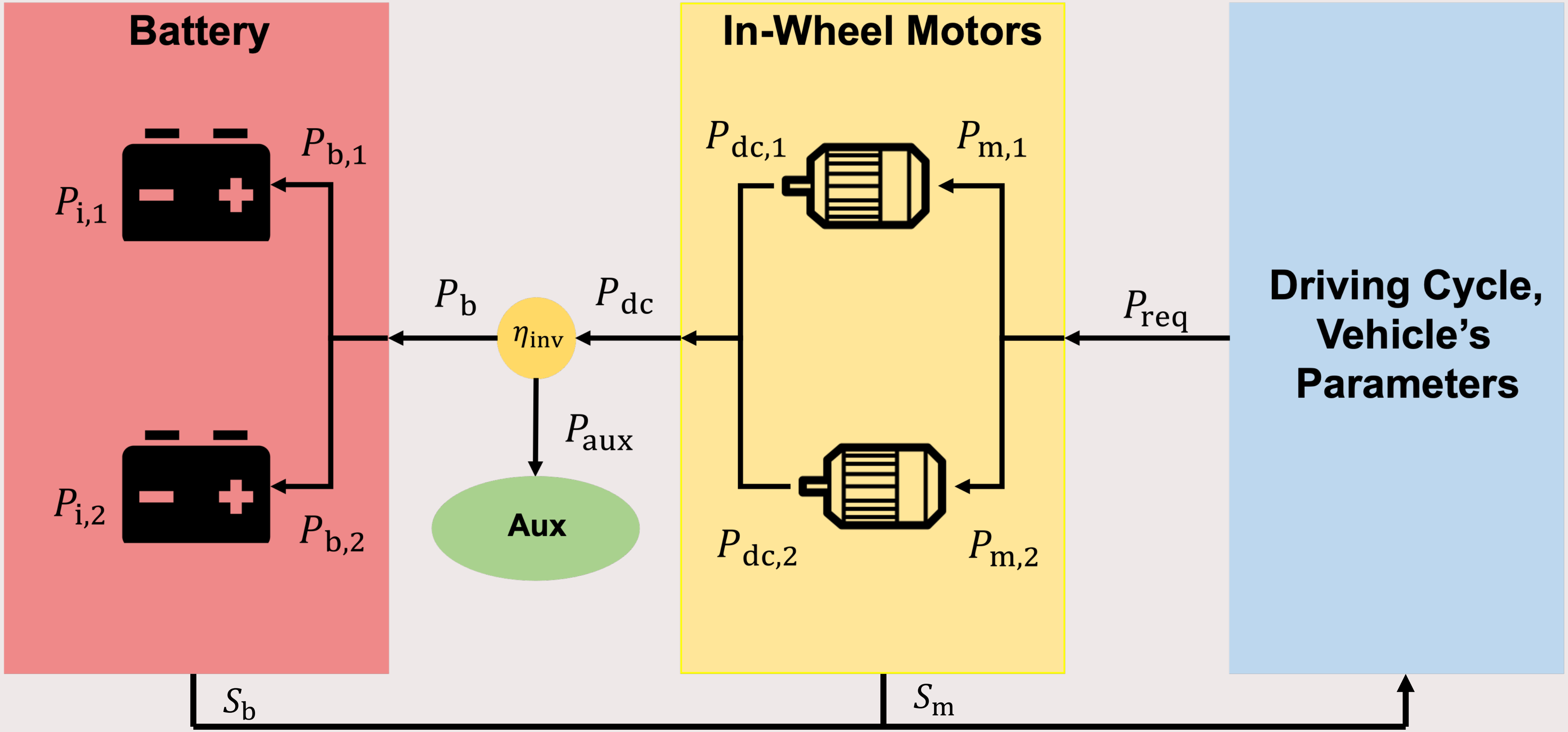


Concurrent Design

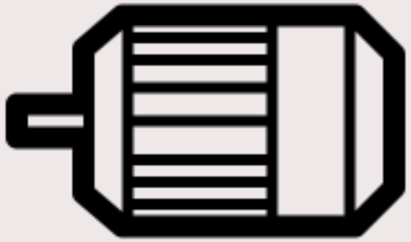
- Design of **family-optimal single-sized modules**
- **Several modules** for **different platforms**
- Optimal compromise between **vehicle-tailored design** and **vehicle choice**



Vehicle model



Motor Model



$$P_{dc} = P_m + S_m P_0(\omega) + \beta(\omega) P_m + \frac{\alpha(\omega)\, P_m^2}{S_m}$$

$$P_{dc} - P_m - S_m P_0(\omega) - \beta(\omega) P_m = \frac{\alpha(\omega)\, P_m^2}{S_m}$$

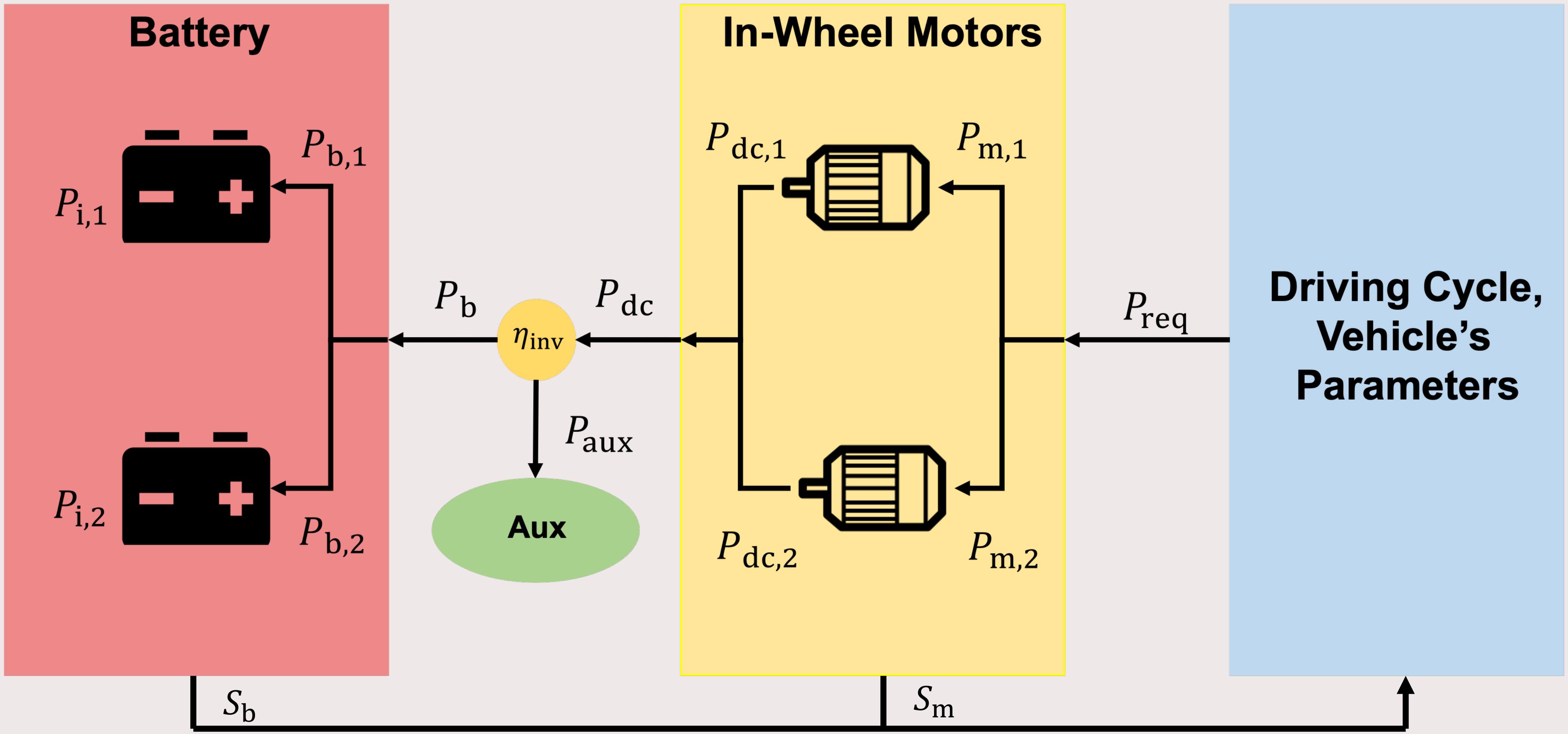
$$P_{dc} - P_m - S_m P_0(\omega) - \beta(\omega) P_m \geq \frac{\alpha(\omega)}{S_m} P_m^2$$

$$xy \geq z^2 \Rightarrow x + y \geq \left\| \begin{matrix} 2z \\ x - y \end{matrix} \right\|_2$$

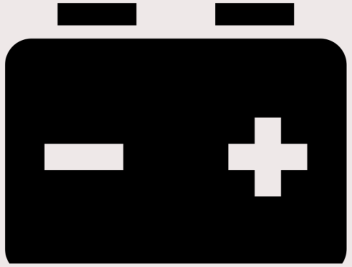
$$\left(P_{dc} - P_m - S_m P_0(\omega) - \beta(\omega) P_m\right) \frac{S_m}{\alpha(\omega)} \geq P_m^2$$

$$P_{dc} - P_m - S_m P_0(\omega) - \beta(\omega) P_m + \frac{S_m}{\alpha(\omega)} \geq \left\| \begin{matrix} 2\, P_m \\ P_{dc} - P_m - S_m P_0(\omega) - \beta(\omega) P_m - \frac{S_m}{\alpha(\omega)} \end{matrix} \right\|_2$$

Vehicle model



Battery Model



$$P_\mathrm{i} = P_\mathrm{b} + \frac{P_\mathrm{i}^2}{P_\mathrm{sc}} \qquad P_\mathrm{sc} = \min_k\{a_k E_\mathrm{b} + b_k S_\mathrm{b}\}$$

$$(P_\mathrm{i} - P_\mathrm{b})P_\mathrm{sc} = P_\mathrm{i}^2$$

$$(P_\mathrm{i} - P_\mathrm{b})P_\mathrm{sc} \geq P_\mathrm{i}^2 \qquad P_\mathrm{sc} \leq \min_k\{a_k E_\mathrm{b} + b_k S_\mathrm{b}\}$$

$$xy \geq z^2 \;\Rightarrow\; x + y \geq \left\| \begin{matrix} 2z \\ x - y \end{matrix} \right\|_2$$

$$(P_\mathrm{i} - P_\mathrm{b})P_\mathrm{sc} \geq P_\mathrm{i}^2$$

$$(P_\mathrm{i} - P_\mathrm{b}) + P_\mathrm{sc} \geq \left\| \begin{matrix} 2P_\mathrm{i} \\ (P_\mathrm{i} - P_\mathrm{b}) - P_\mathrm{sc} \end{matrix} \right\|_2$$

Optimization Problem Formalization

$$\min c_{\mathrm{e}} \sum_{i=1}^{N_{\mathrm{v}}} \left(E_{\mathrm{b},i}(0) - E_{\mathrm{b},i}(T) \right)$$

Subject To:

Common Constraints

$$S_{\mathrm{m}} \epsilon \left[S_{\mathrm{m,min}}, S_{\mathrm{m,max}} \right]$$
$$S_{\mathrm{b}} \epsilon \left[S_{\mathrm{b,min}}, S_{\mathrm{b,max}} \right]$$

Vehicle Specific Constraints

Vehicle I

$$M = M_0 + S_{\mathrm{m}} M_{\mathrm{m0}} + S_{\mathrm{b}} M_{\mathrm{b0}}$$
Vehicle & Powertrain Constraints
Performance Constraints

Vehicle II

$$M = M_0 + S_{\mathrm{m}} M_{\mathrm{m0}} + S_{\mathrm{b}} M_{\mathrm{b0}}$$
Vehicle & Powertrain Constraints
Performance Constraints

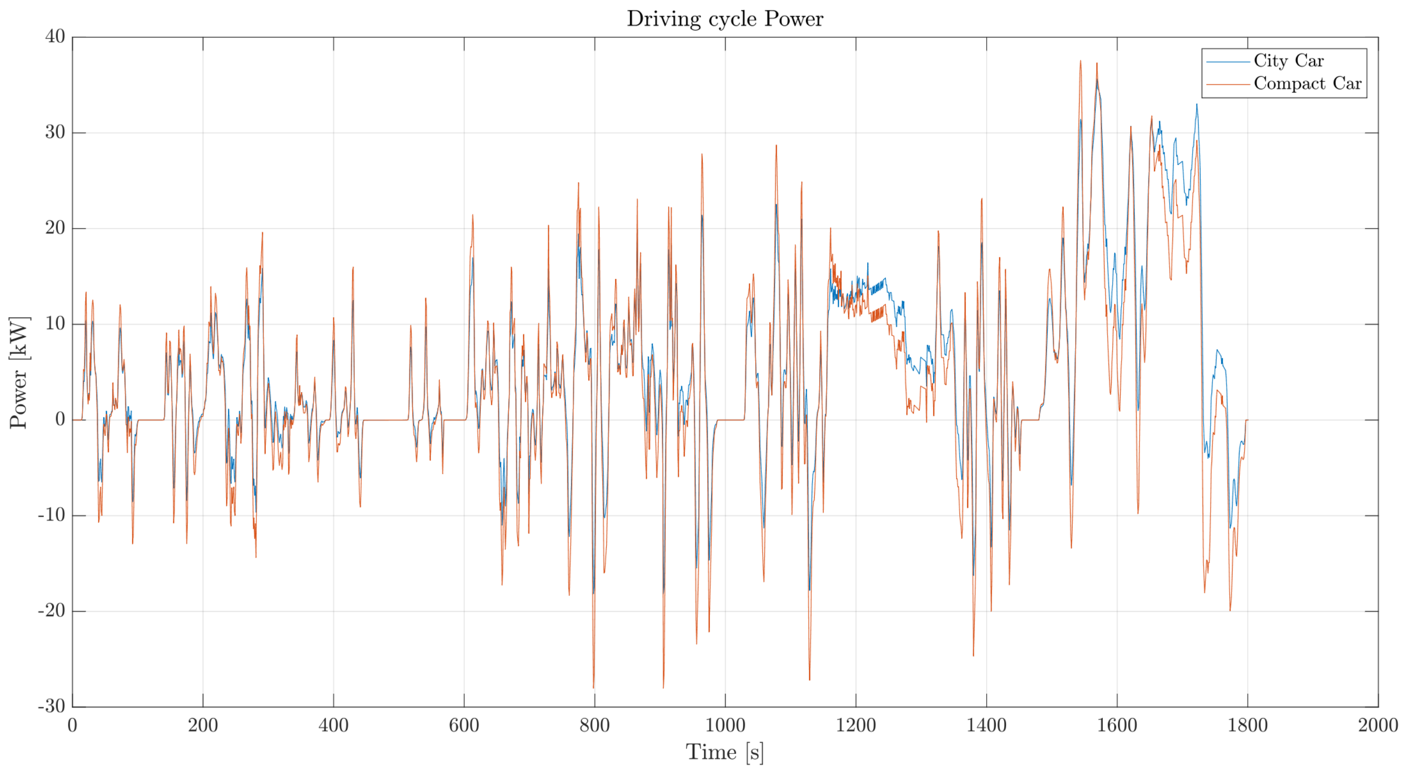
Vehicle N_{v}

$$M = M_0 + S_{\mathrm{m}} M_{\mathrm{m0}} + S_{\mathrm{b}} M_{\mathrm{b0}}$$
Vehicle & Powertrain Constraints
Performance Constraints

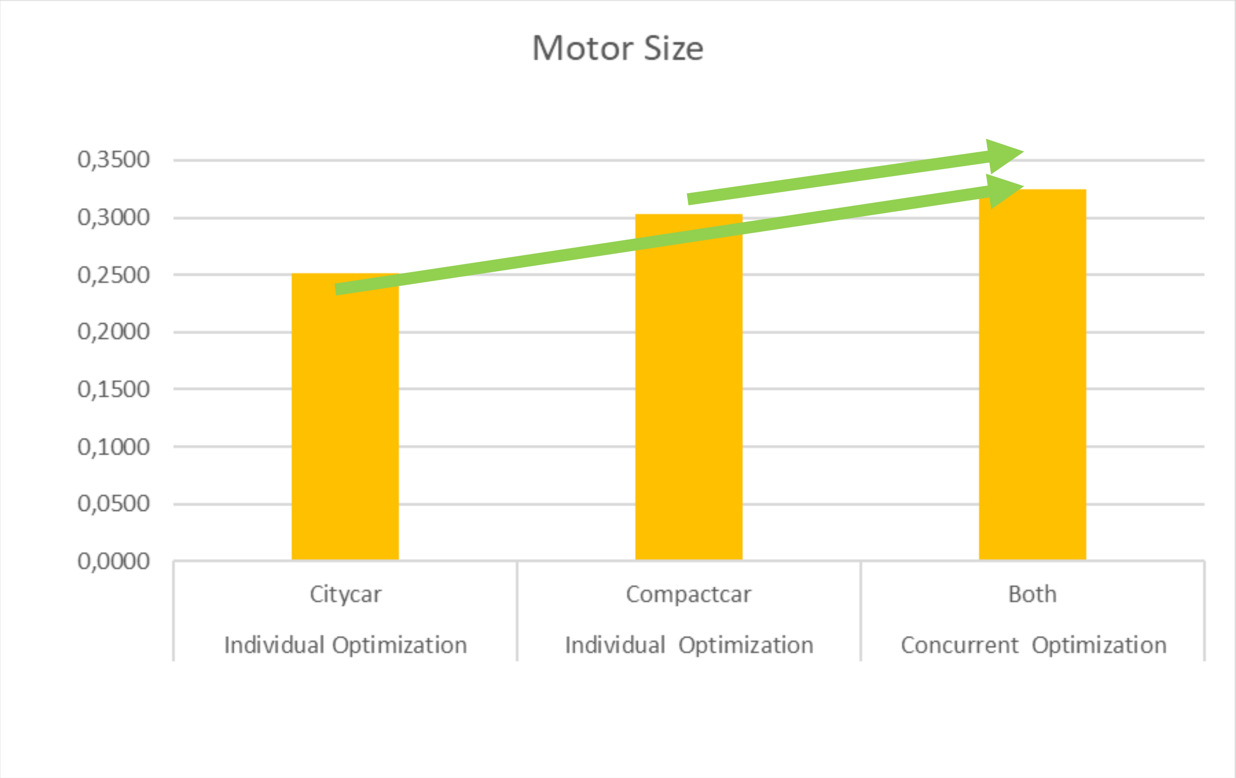
Results

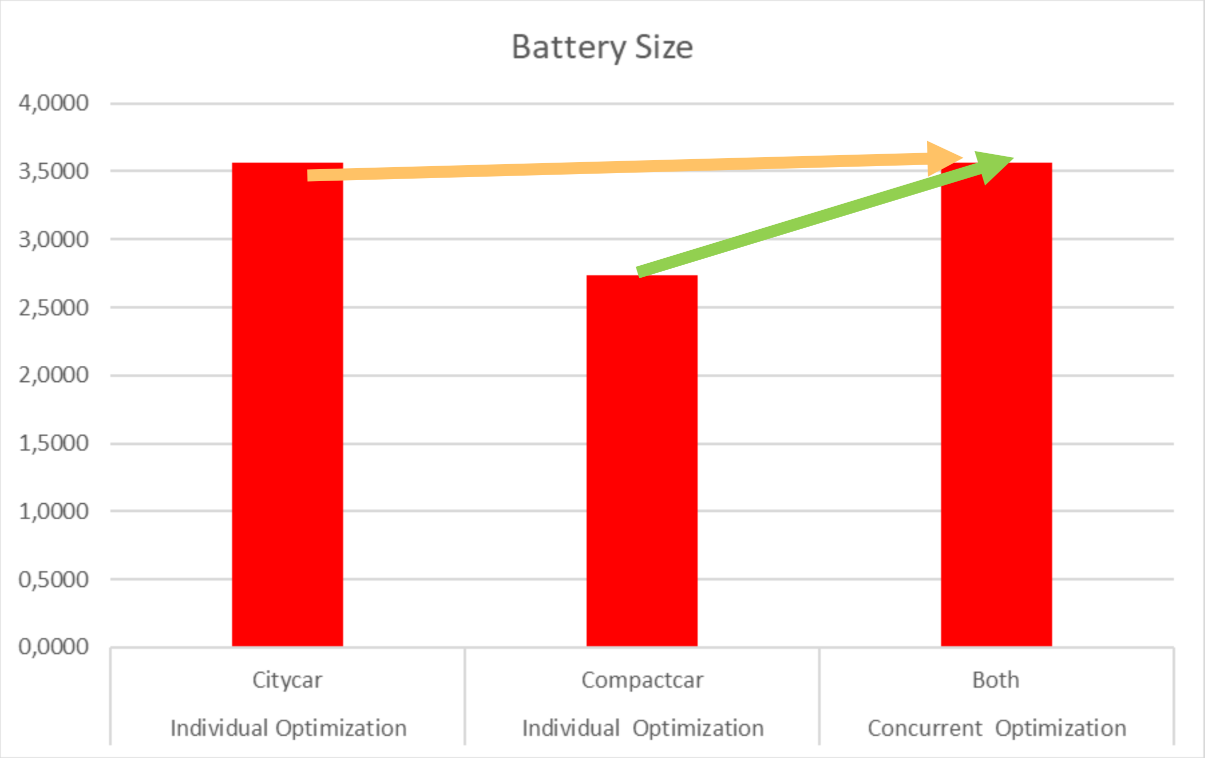
We consider the Class 3 **Worldwide harmonized Light-duty vehicles Test Cycle (WLTC)** for the speed and acceleration trajectories.

We parse it with **YALMIP** and solve it to **global optimality** with **MOSEK**, in approximately 2 s.



Concurrently optimized modules



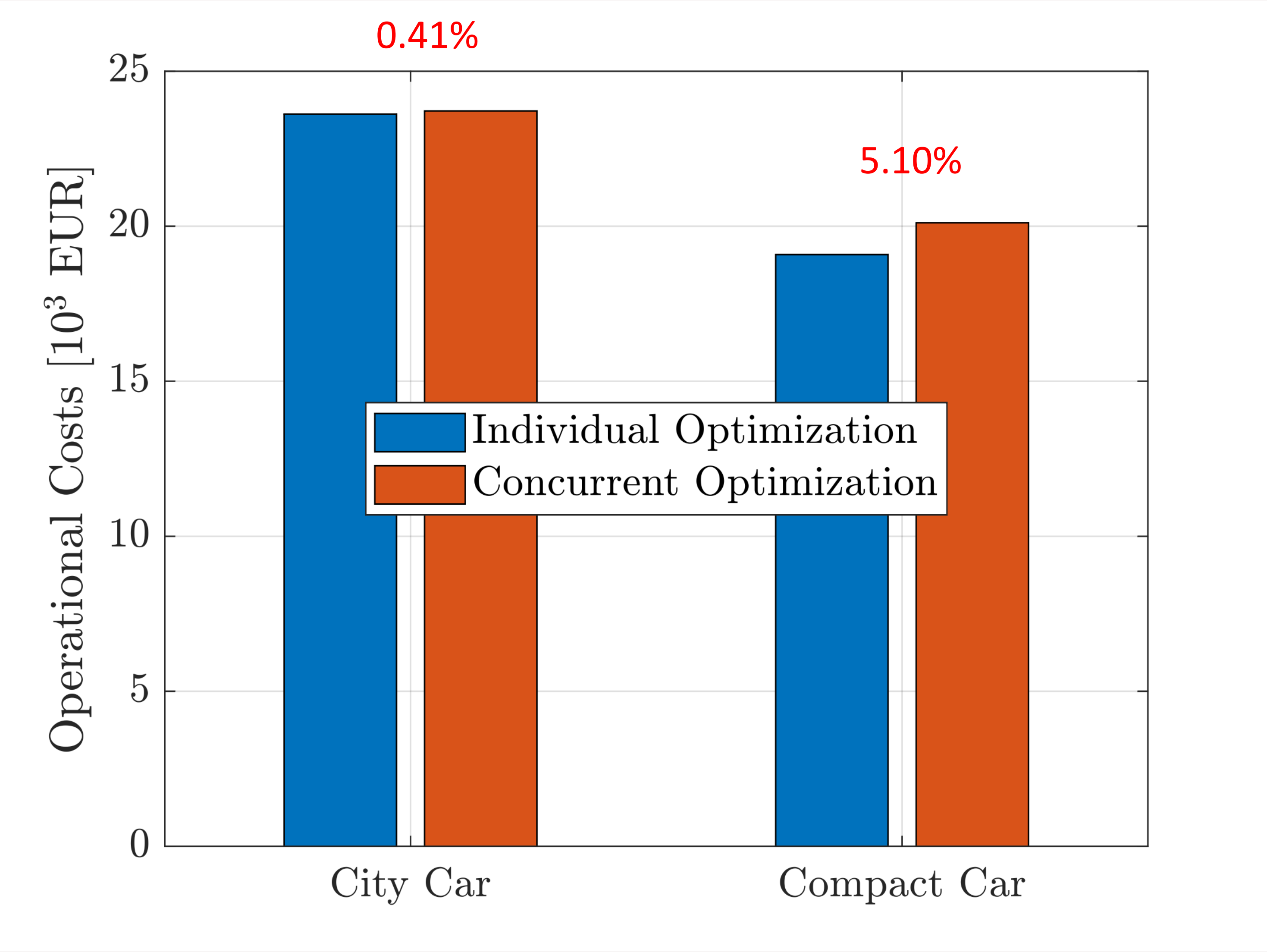


Operational costs

Sizing powertrain components **concurrently** only causes an **average increase** of the operation costs of **2.76%** for the family, compared to the individual vehicle-tailored optimization.

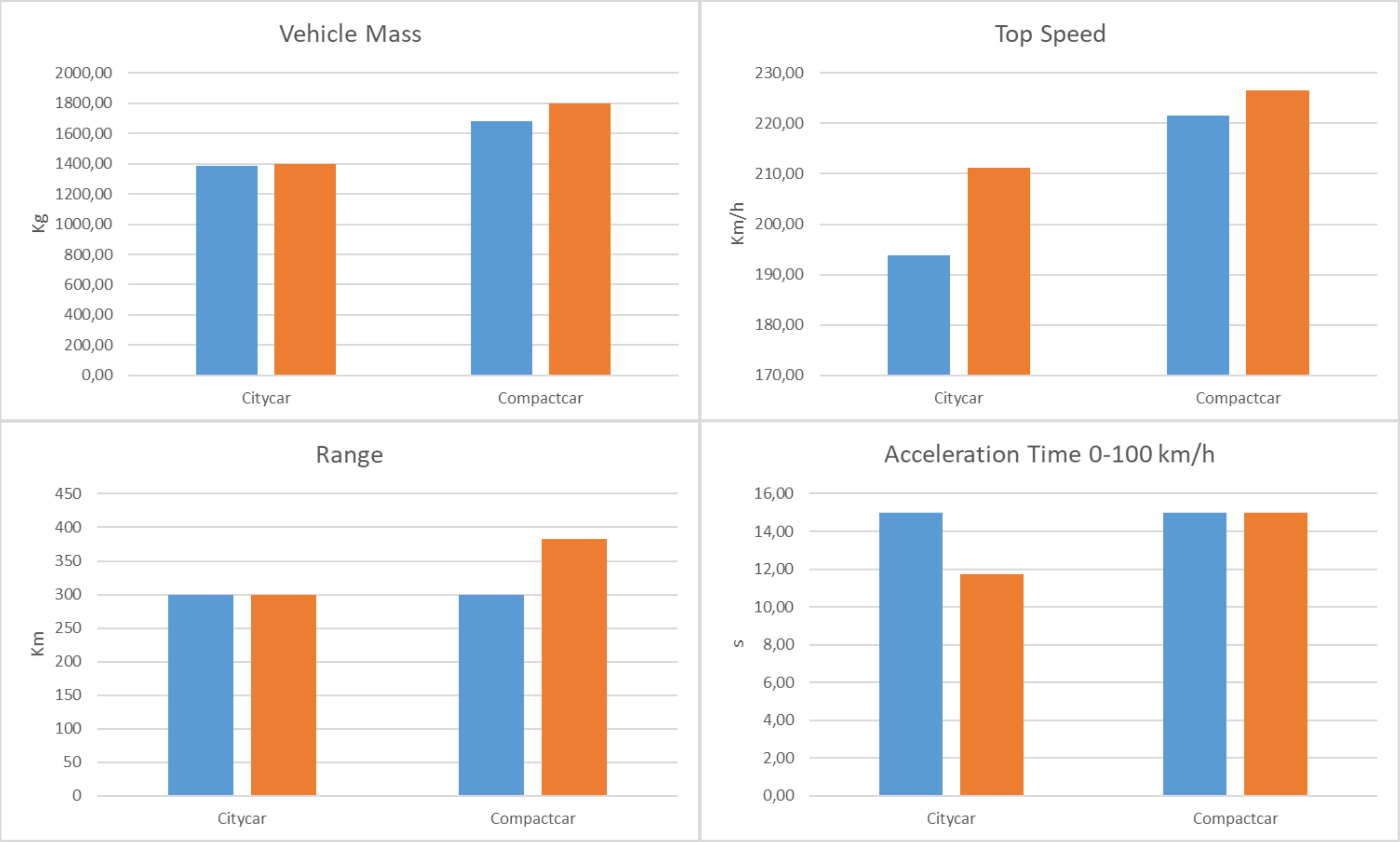
It is expected that this value will be largely outperformed by the benefits derived from using a single component shared by the entire product family.

Both approaches obtain similar results for the small city car, with a limited variation of **0.41%**, whilst the larger compact car shows a difference of **5.10%**.



Performance

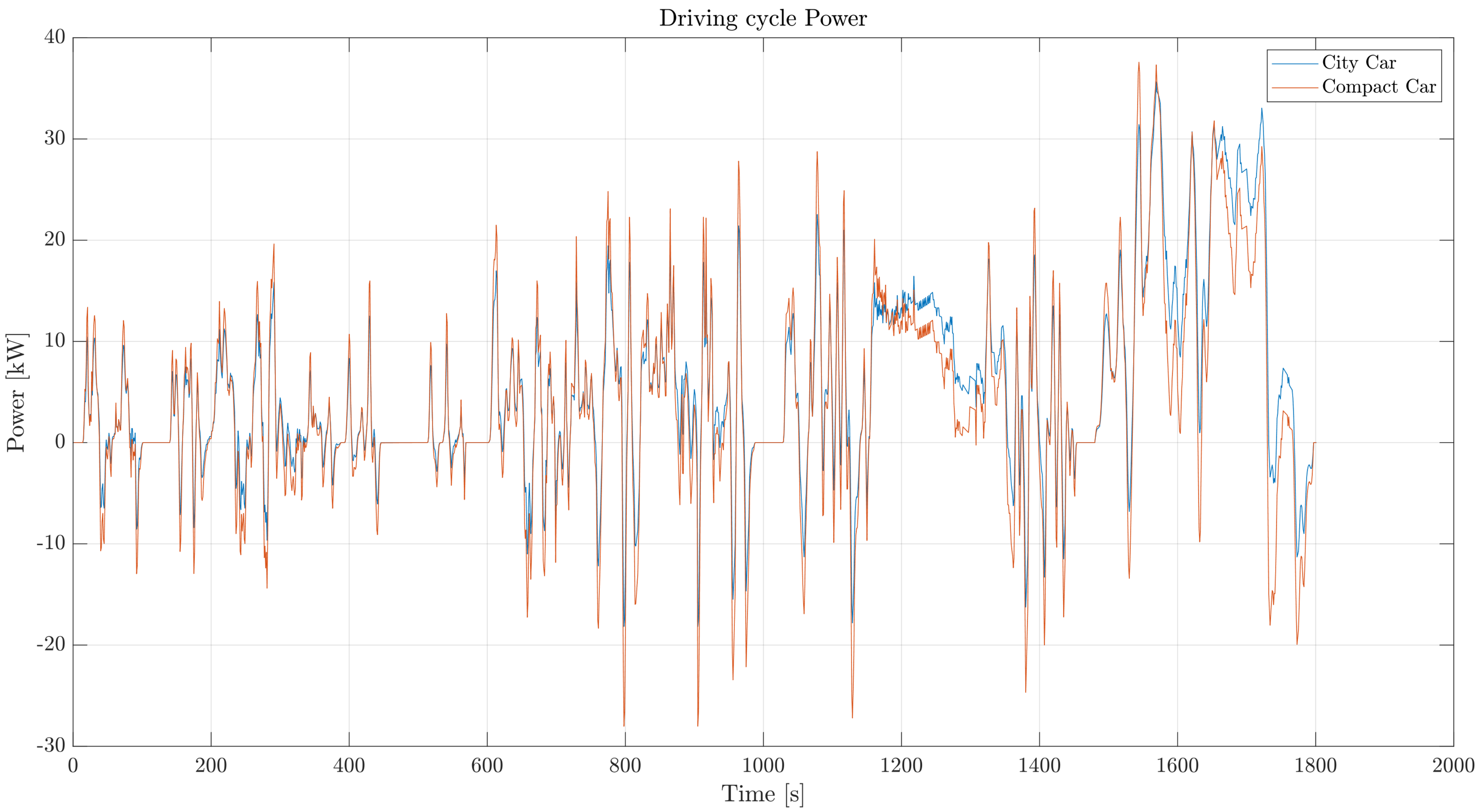
For both vehicles, the **increase in operational cost** is accompanied by an **improvement in performance**, such as a shorter acceleration time, an extended range, or a higher top speed

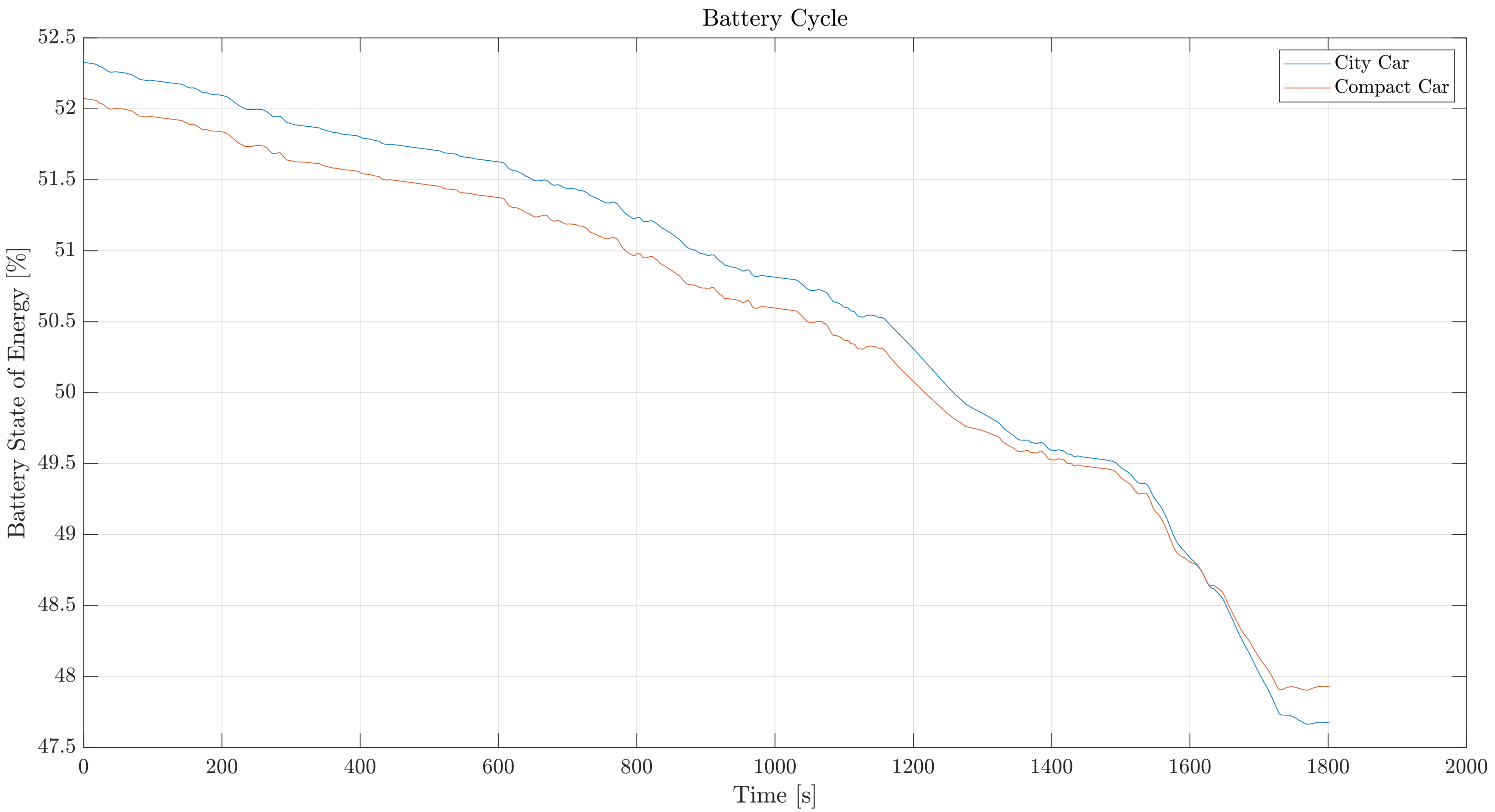


Future Work

- Consider **multiplicity** as a variable in the optimization problem
- Develop a cost model for benefits induced by the **economy of scale**
- Consider the emissions during **production phase** of the components
- Introduce the effect of **learning curves** on costs and emissions

Thank You


Driving cycle Power
City Car
Compact Car
Power [kW]
Time [s]
40
30
20
10
0
-10
-20
-30
0
200
400
600
800
1000
1200
1400
1600
1800
2000


Battery Cycle
City Car
Compact Car
52.5
52
51.5
51
50.5
50
49.5
49
48.5
48
47.5
Battery State of Energy [%]
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Time [s]