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POWERTECH ENGINEERING

GLOBAL GT CONFERENCE 2021
October 19-21, 2021 – Virtual Event

Numerical Assessment of Adaptive-ECMS Strategies for a Gasoline Hybrid Electric Vehicle on Type Approval and RDE Driving Cycles

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Agenda

1. Introduction
2. Case Study
3. Adaptive ECMS
4. Results
5. Conclusions

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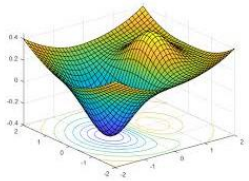
1. Introduction

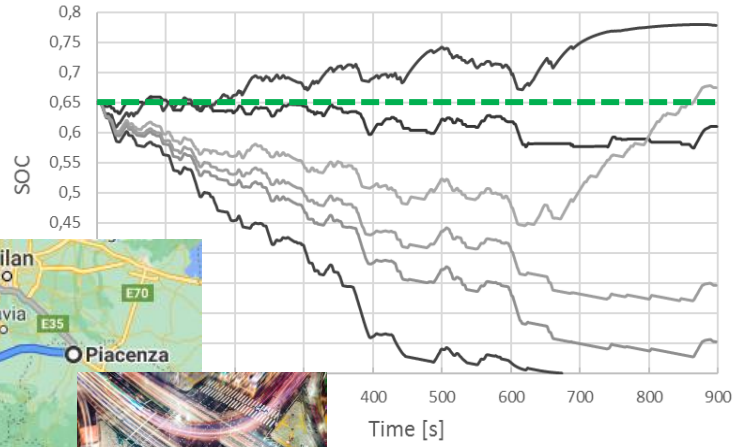


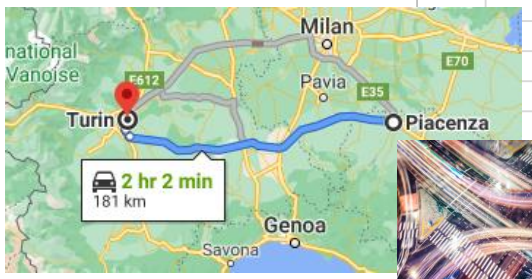
Vehicle Electrification & Energy Management Strategies

Numerical simulation is the elective ground for development and testing of control strategies

V-Cycle

GT





AIM

Develop Energy Management Systems (based on **Adaptive-ECMS)** that guarantee **Charge Sustaining** operation on **Type Approval** and **RDE driving cycles**

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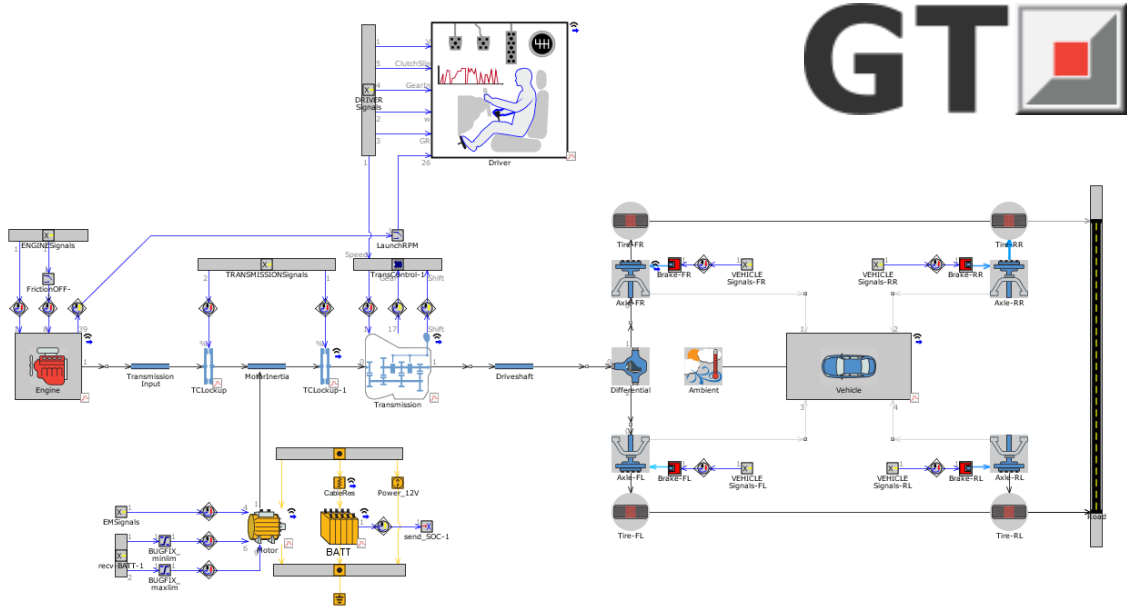
2. Case Study

Vehicle | Mid-SUV, 1500 kg, 137 kW @100 km/h

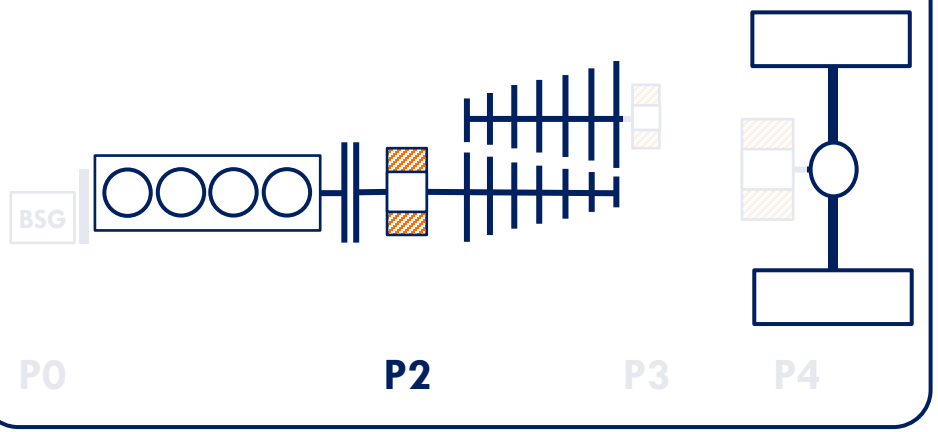
ICE | 4Cyl 1.8L TC GDI – 172 kW

Electric Motor | 28.5 kW, 200 Nm

Battery | 168 V, 800 Wh



Hybrid architecture



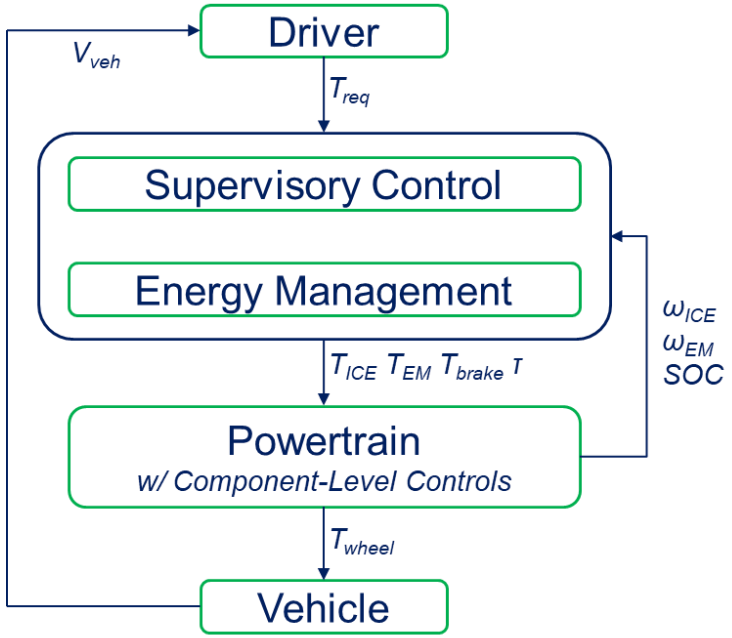
- Map-based powertrain (ICE and EM)
- Thevenin Equivalent electric circuit battery
- 0D Driveline

- ECU and vehicle controllers:
  - Fuel cut-off
  - S&S
  - Regenerative Braking

2. Case Study

- **Energy Management Strategy**
  - **Supervisory Control:** determines the operating mode (ICE-only, ICE+EMs, EV, etc.)
  - **Energy Management:** splits power demand (from supervisory) between ICE and EM(s)

Equivalent Consumption Minimization Strategy (ECMS)

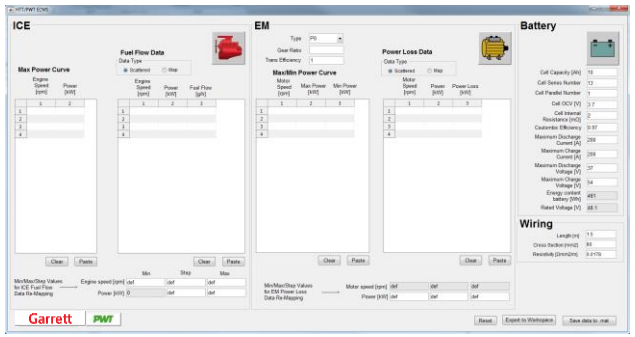


Engine Fuel Flow

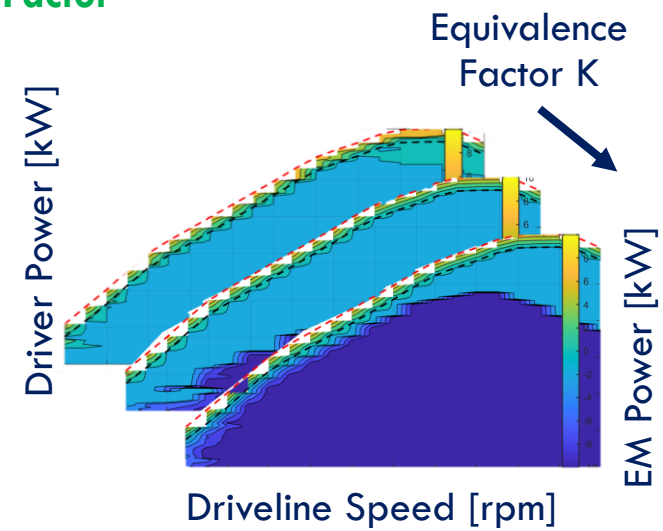
$$\dot{m}_{fuel\ eqv} = \dot{m}_{fuel} + K \cdot P_{batt}$$

Fuel Flow 'equivalent' Electric Power

K → Equivalence Factor



Offline ECMS Powersplit Map Generation



2. Case Study

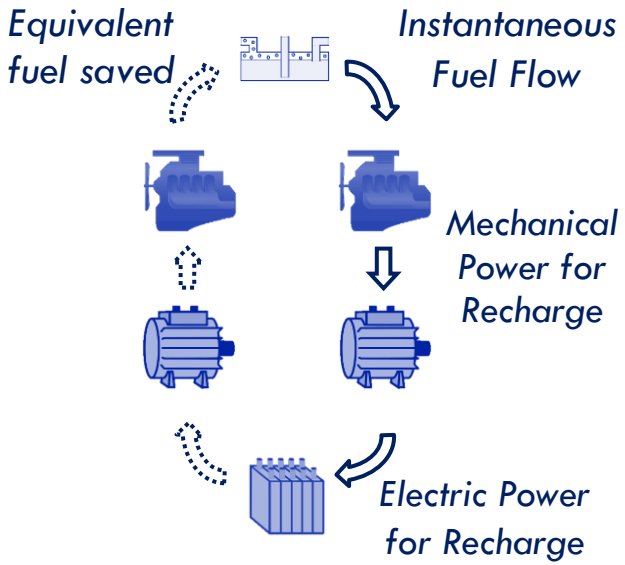
- **Equivalence factor K**

Represents the **chain of efficiency**

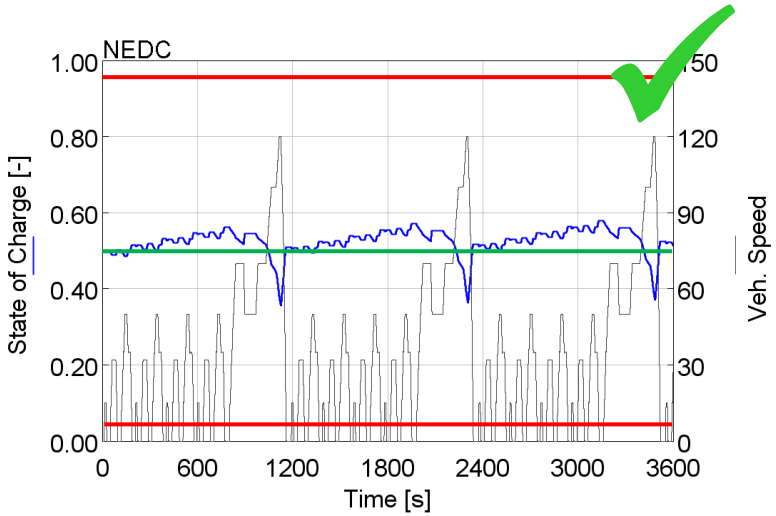
Depends on **operating conditions**

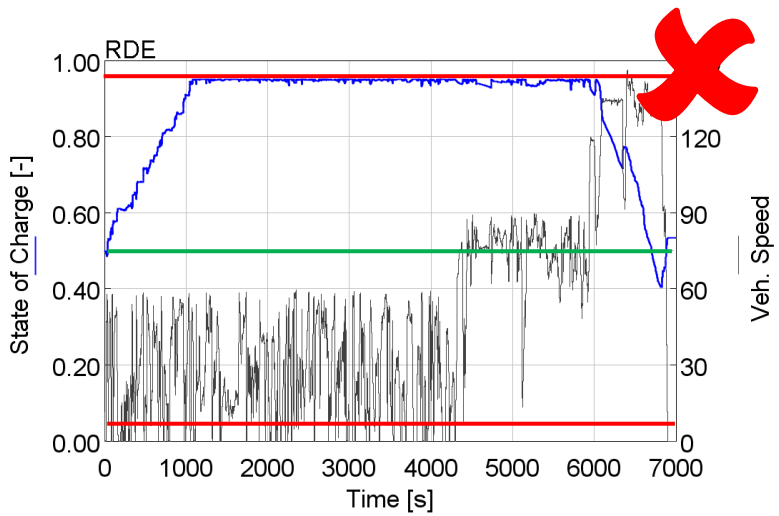
Affects **charge sustainability** and **strategy effectiveness**

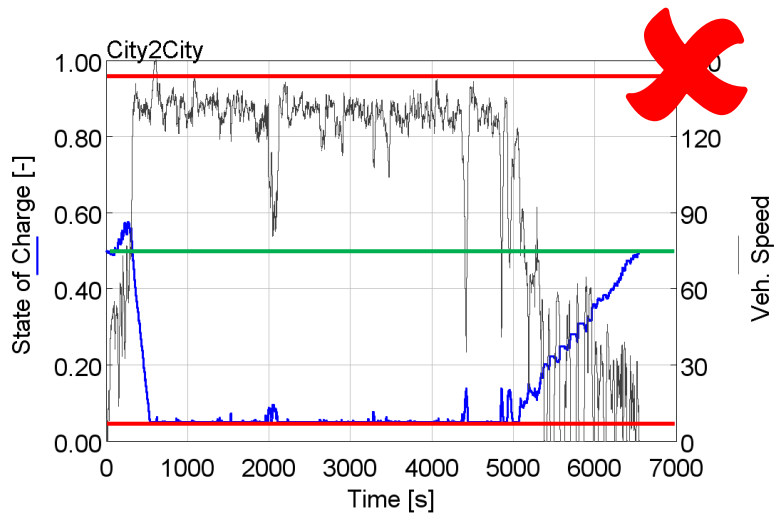
Past, present, future powertrain efficiency



- **Simulations with <u>fixed</u> K factor:**







Agenda

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3. **Adaptive ECMS**
4. Results
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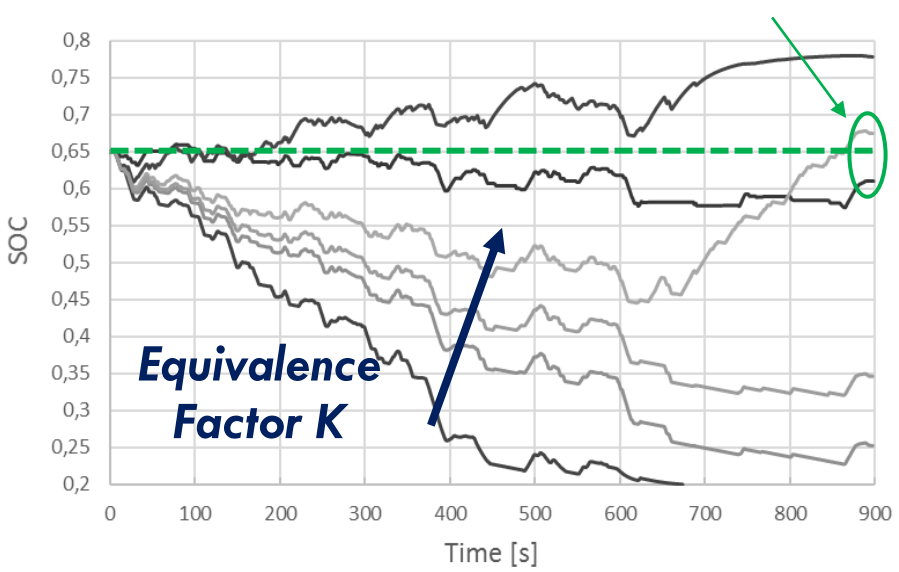
3. Adaptive ECMS

- **Adaptation techniques:**

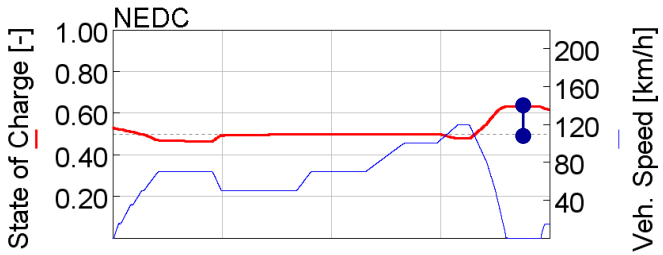
  A. Adaptation of the Equivalence Factor K using SOC feedback

  B. Driving Pattern Recognition

  C. Driving Pattern Prediction

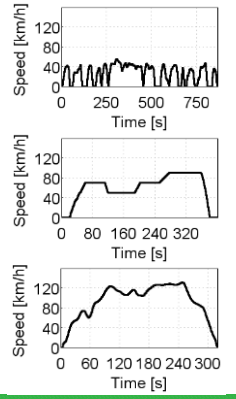


A Adaptation of K using the SOC Feedback (A-ECMS)



→ **Updated K**

B Driving Pattern Recognition (DPR-ECMS)



→ *Urban*

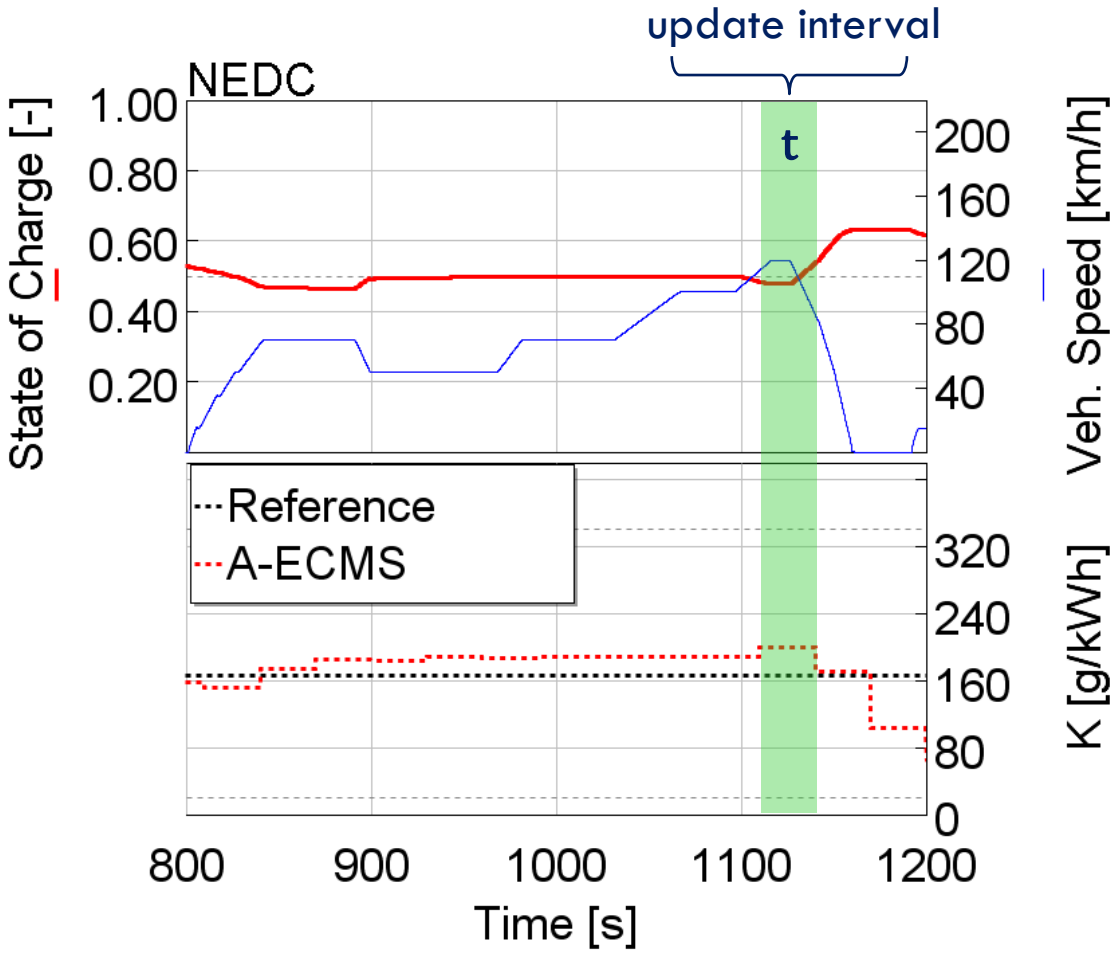
→ *Extra-Urban*

→ *Highway*

→ **Updated K**

3. Adaptive ECMS

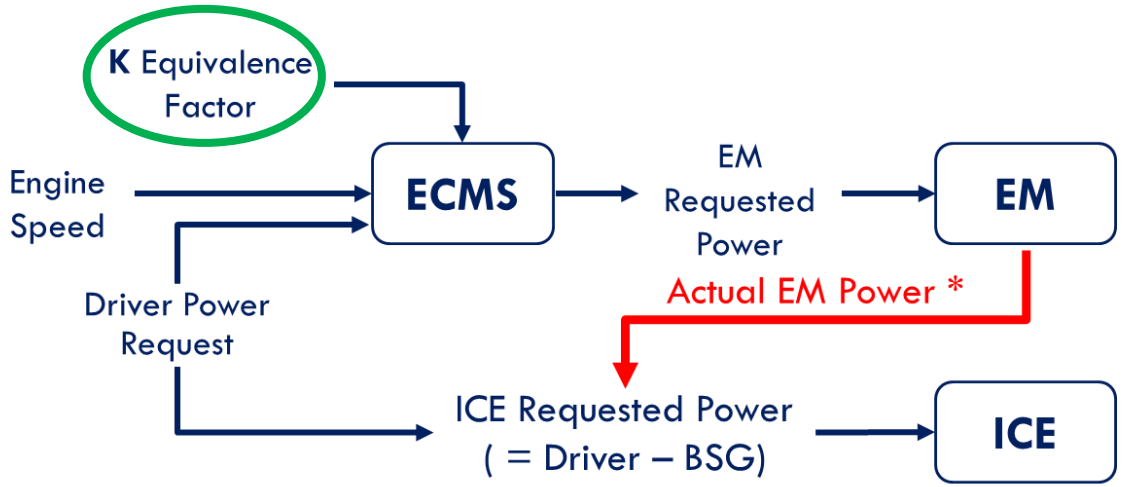
A Adaptation of K using the SOC Feedback (A-ECMS)



$$K_t(SOC,T) = \frac{K_{t-1} + K_{t-2}}{2} + C_P^d\left(SOC_{tgt} - SOC(T)\right)$$

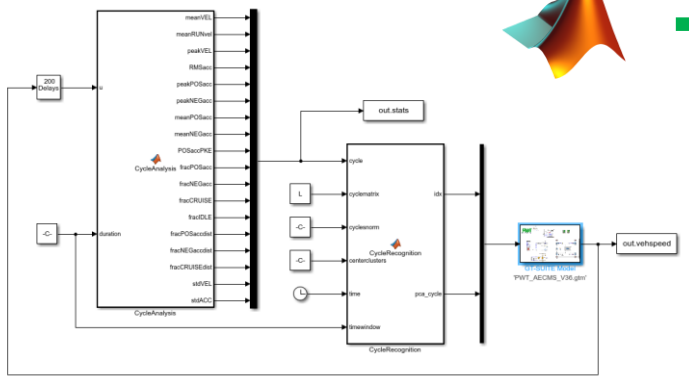
'Memory' term

Proportional term



3. Adaptive ECMS

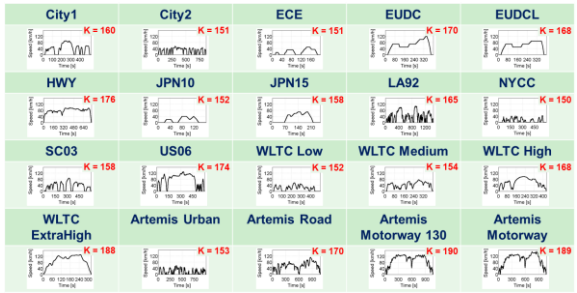
B Driving Pattern Recognition (DPR-ECMS)



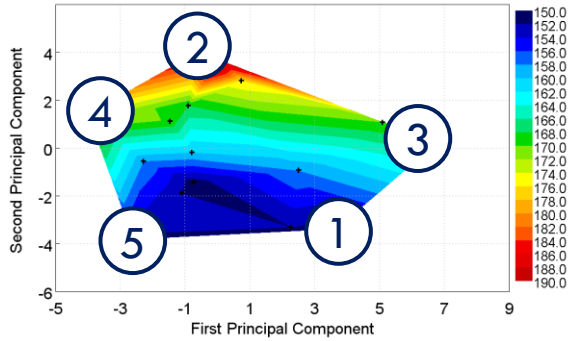
Controller Development

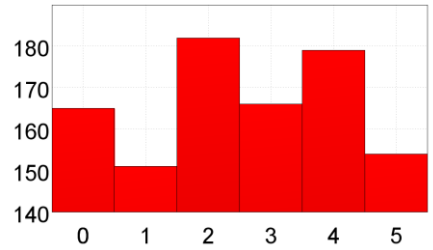
20 Type Approval
driving cycles

Assessment of **charge sustaining K** ⇨ **Statistical analysis** of 18 driving metrics ⇨ **PCA** & definition of **5 Driving Pattern cluster** ⇨ Attribution of **average K** for each DP cluster



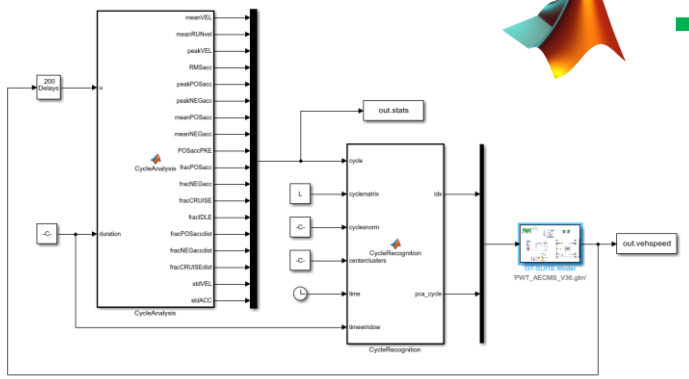
Average Run velocity, max positive acceleration, cruise fraction …





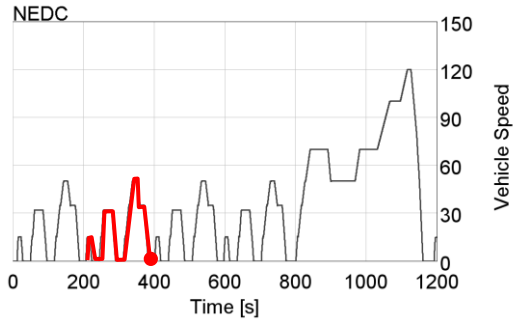
3. Adaptive ECMS

B Driving Pattern Recognition (DPR-ECMS)



Controller Operation

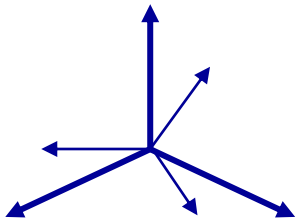
Vehicle velocity is tracked (last 200 s)



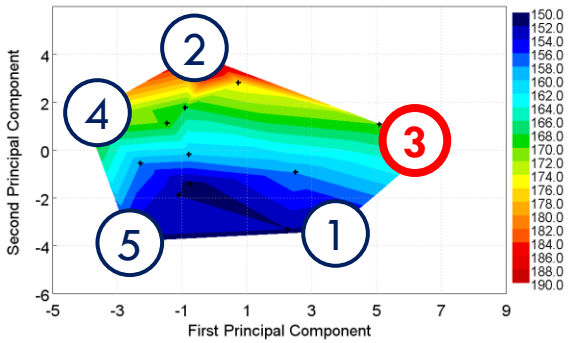
Driving metrics are computed

Average Run velocity, max positive acceleration, cruise fraction …

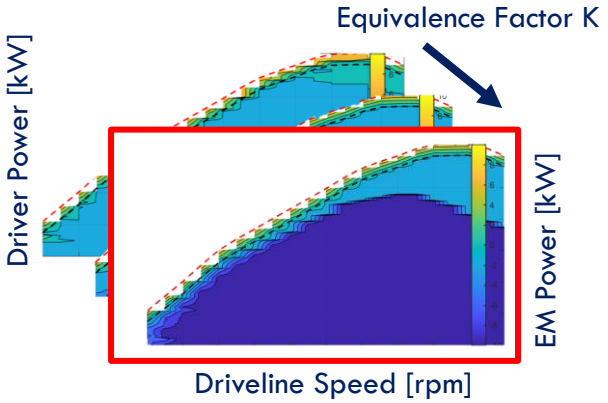
Transformation to **PCA coordinates**



Closest cluster is identified



Selection of **ECMS** maps with **equivalence factor K**



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4. Results

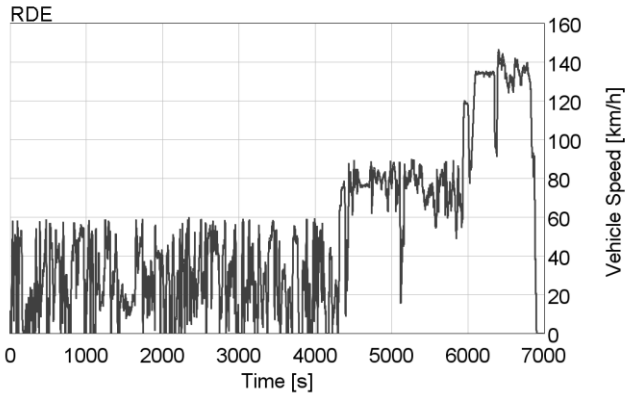
- **Test matrix**
  - The A-ECMS controllers are compared to a Reference vehicle featuring ECMS with a **Fixed Equivalence Factor K**

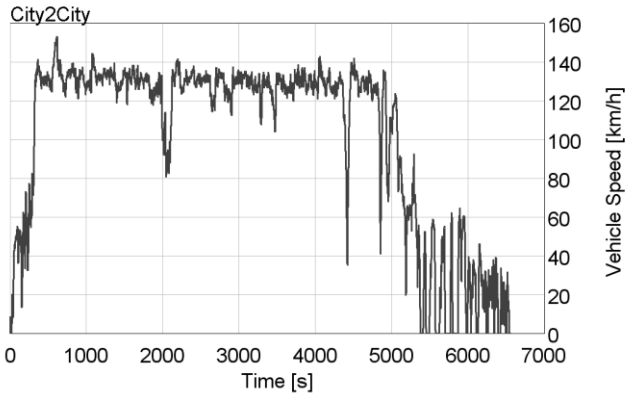
Reference
ECMS with fixed K

Case A
A-ECMS based on SOC feedback

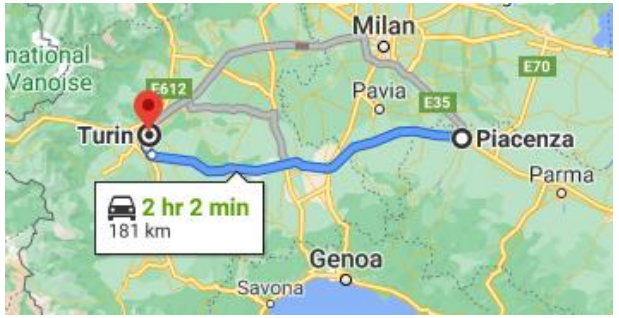
Case B
A-ECMS based on DPR

  - Different Type Approval and RDE driving cycles are performed:
    - **3xNEDC**, 3xWLTC, 3xRTS-95, **1xRDE, 1xCity2City**





City2City



4. Results

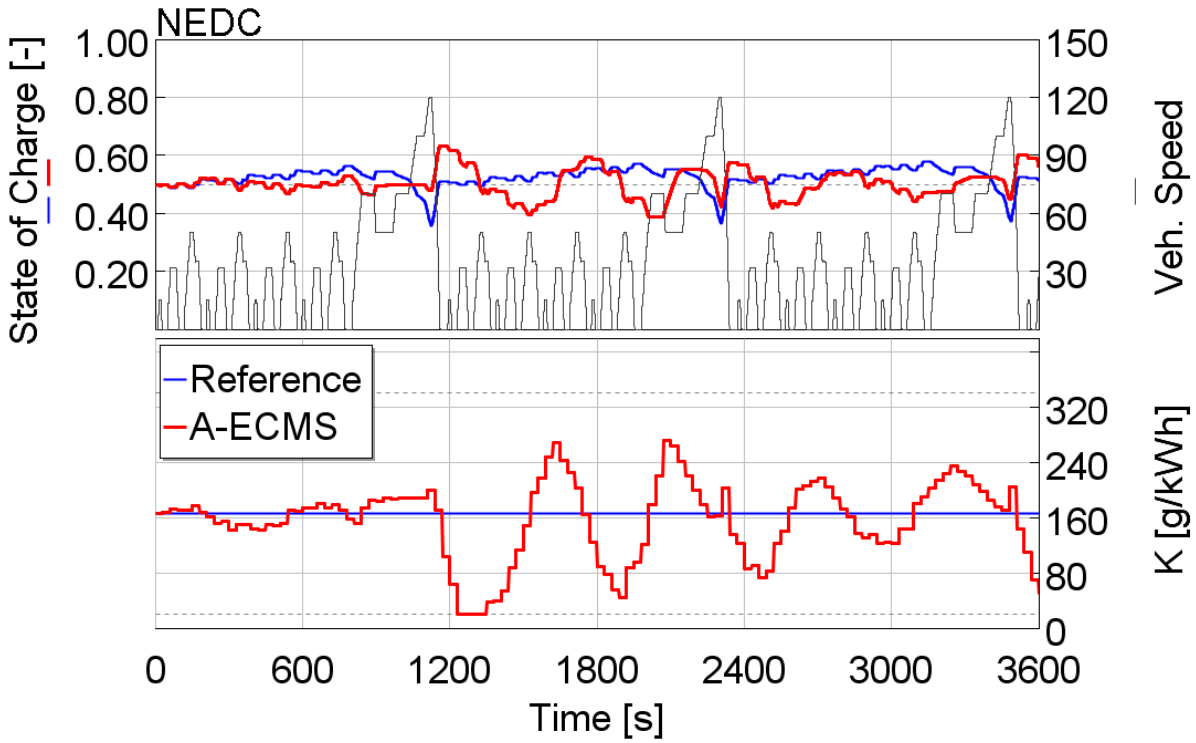
- Driving Cycle: **NEDC**

Reference
ECMS with fixed K

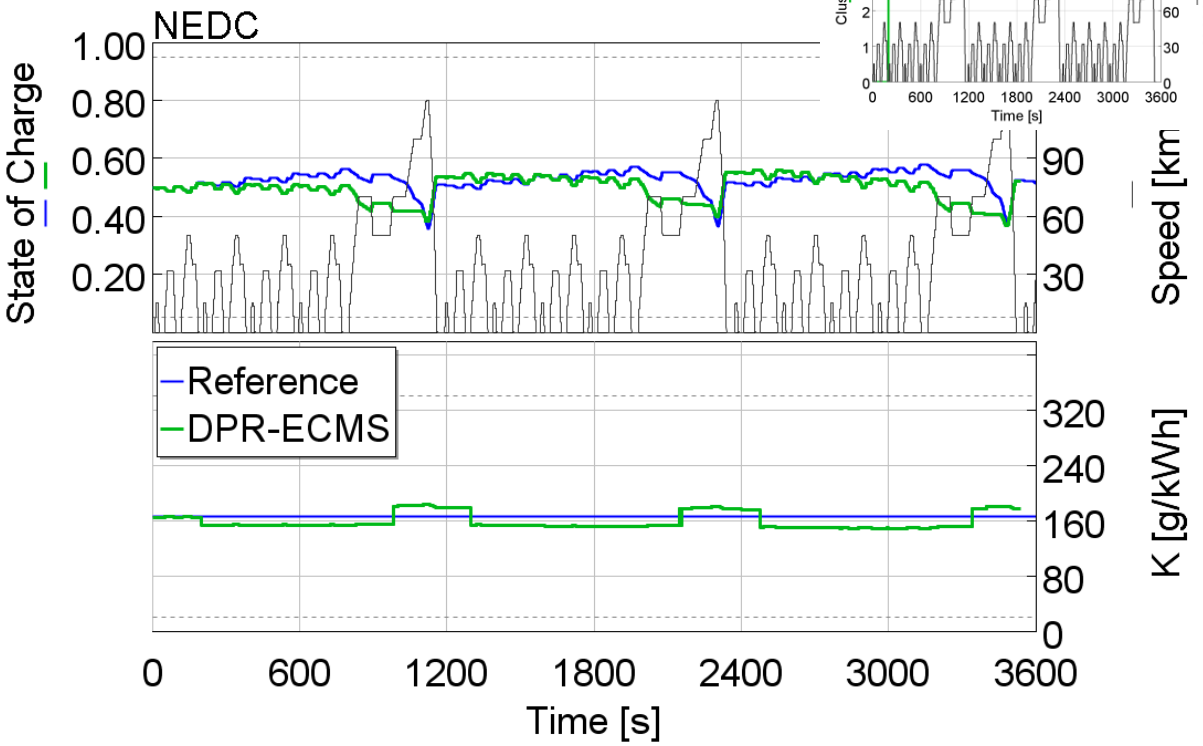
Case A
A-ECMS based on SOC feedback

Case B
A-ECMS based on DPR

A Adaptation of K using the SOC Feedback (A-ECMS)



B Driving Pattern Recognition (DPR-ECMS)



4. Results

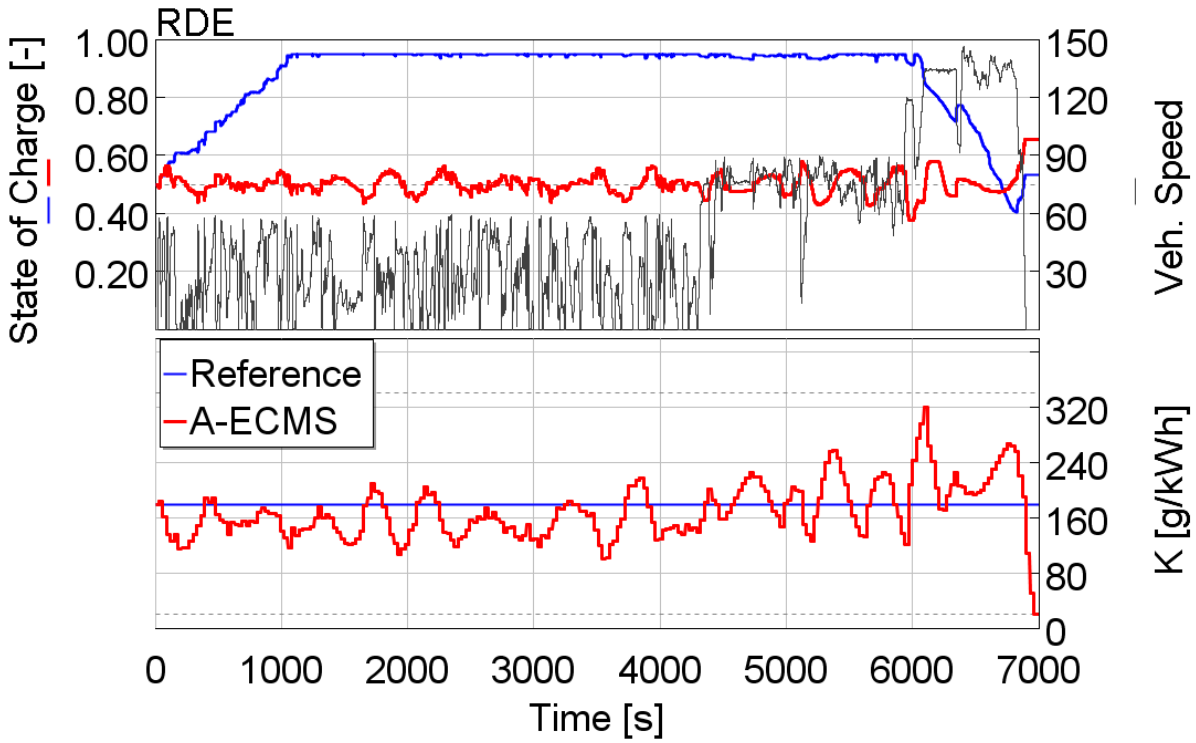
- Driving Cycle: **RDE**

Reference
ECMS with fixed K

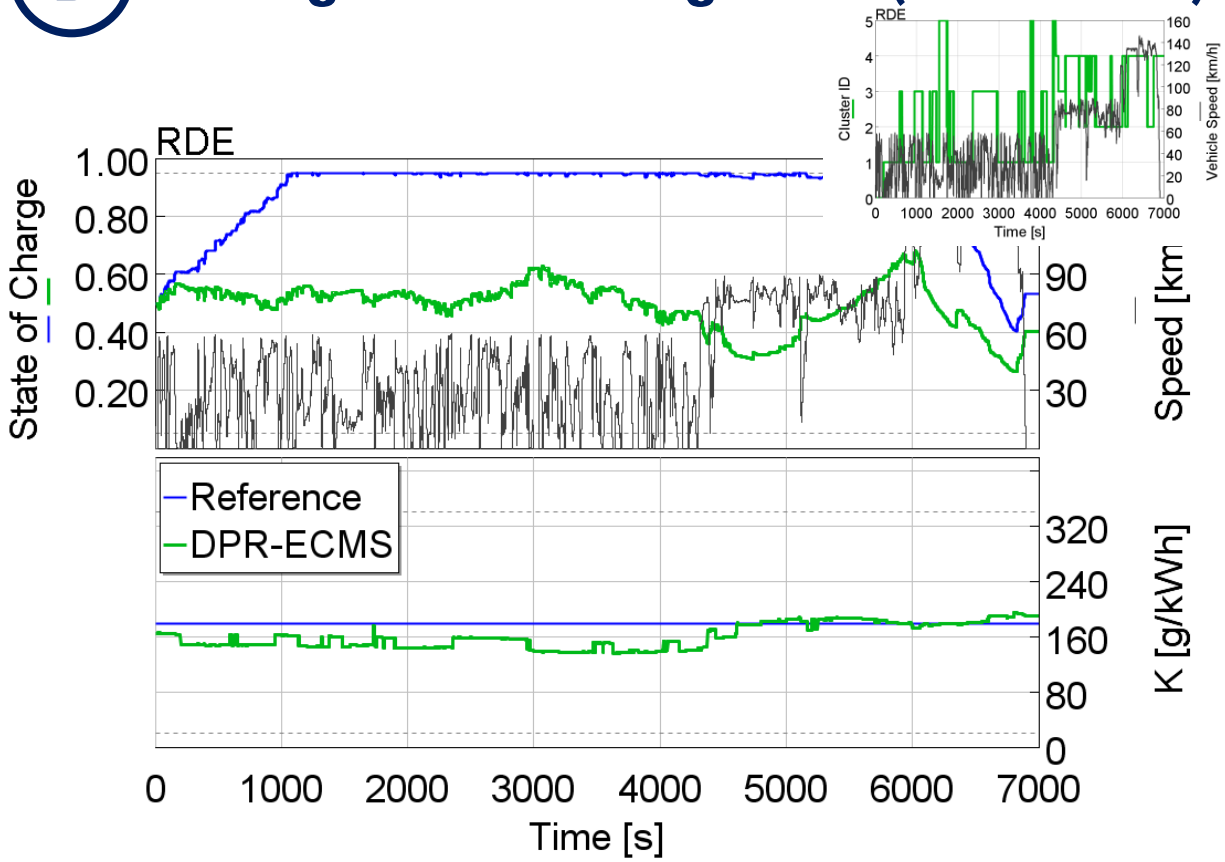
Case A
A-ECMS based on SOC feedback

Case B
A-ECMS based on DPR

A Adaptation of K using the SOC Feedback (A-ECMS)



B Driving Pattern Recognition (DPR-ECMS)



4. Results

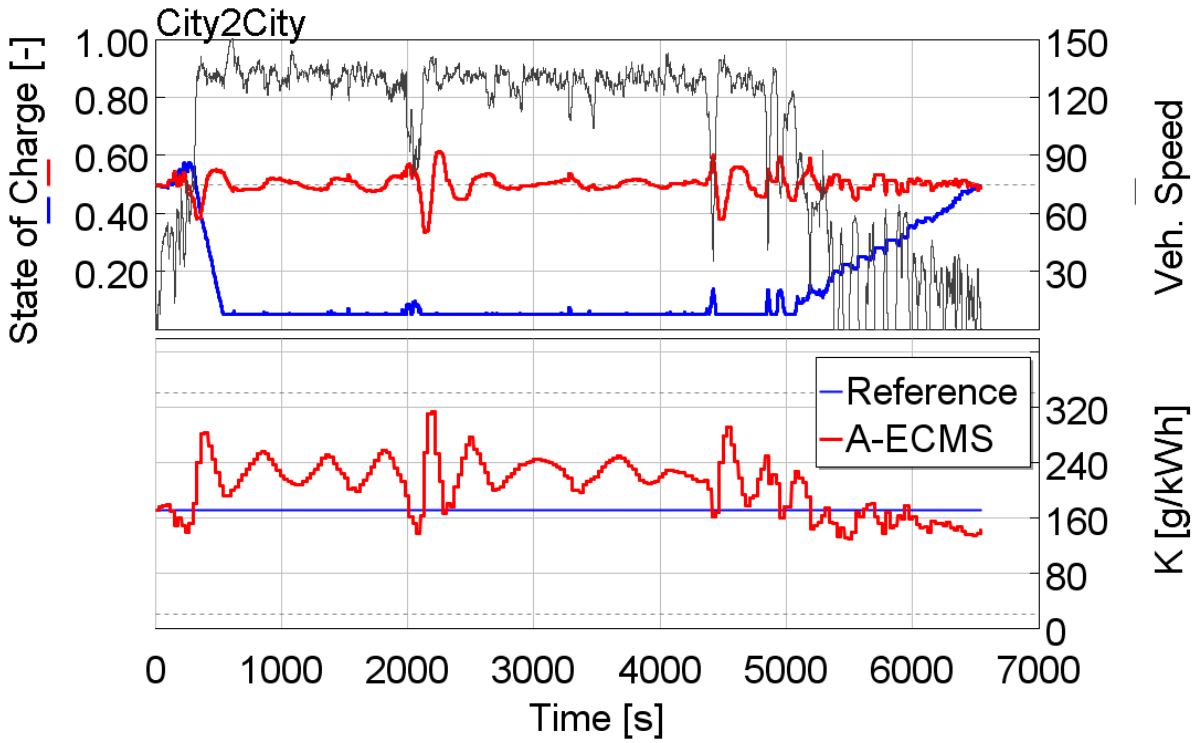
- Driving Cycle: **City2City**

Reference
ECMS with fixed K

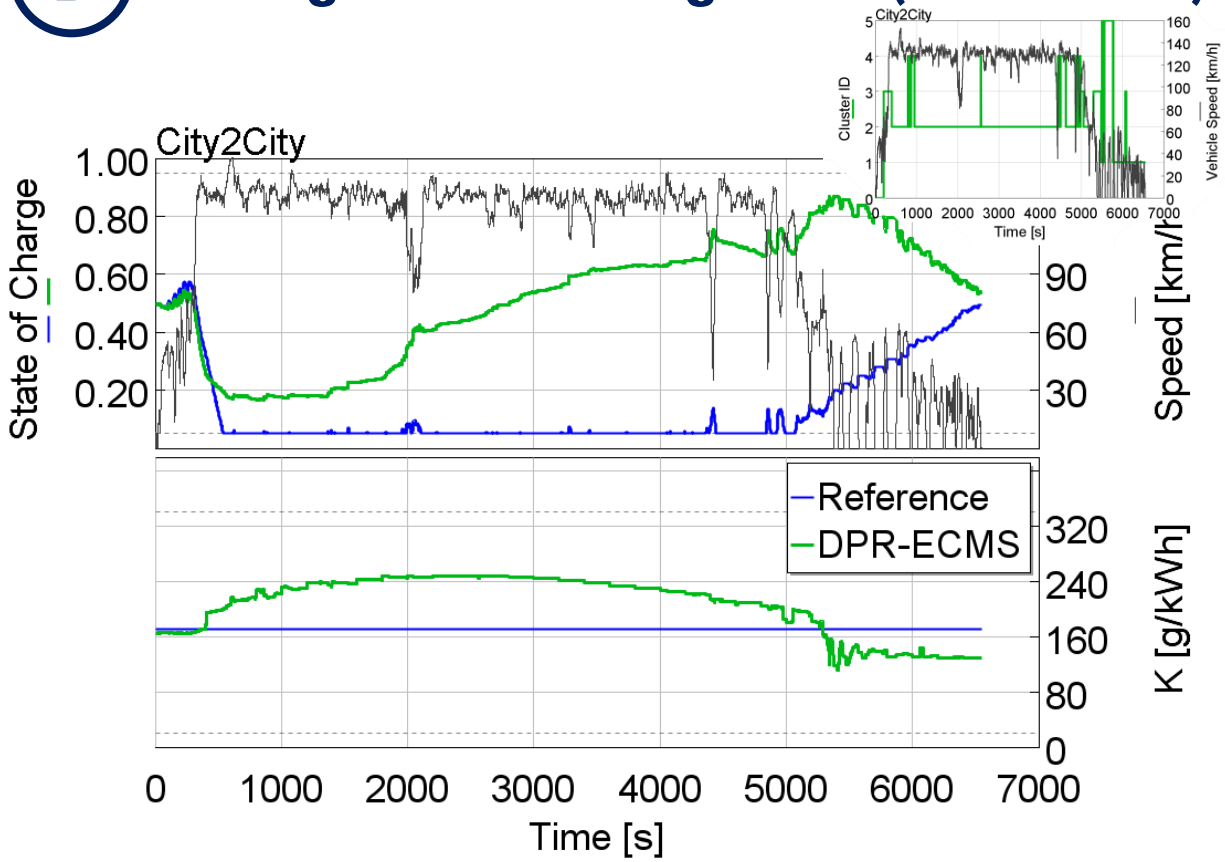
Case A
A-ECMS based on SOC feedback

Case B
A-ECMS based on DPR

A Adaptation of K using the SOC Feedback (A-ECMS)



B Driving Pattern Recognition (DPR-ECMS)



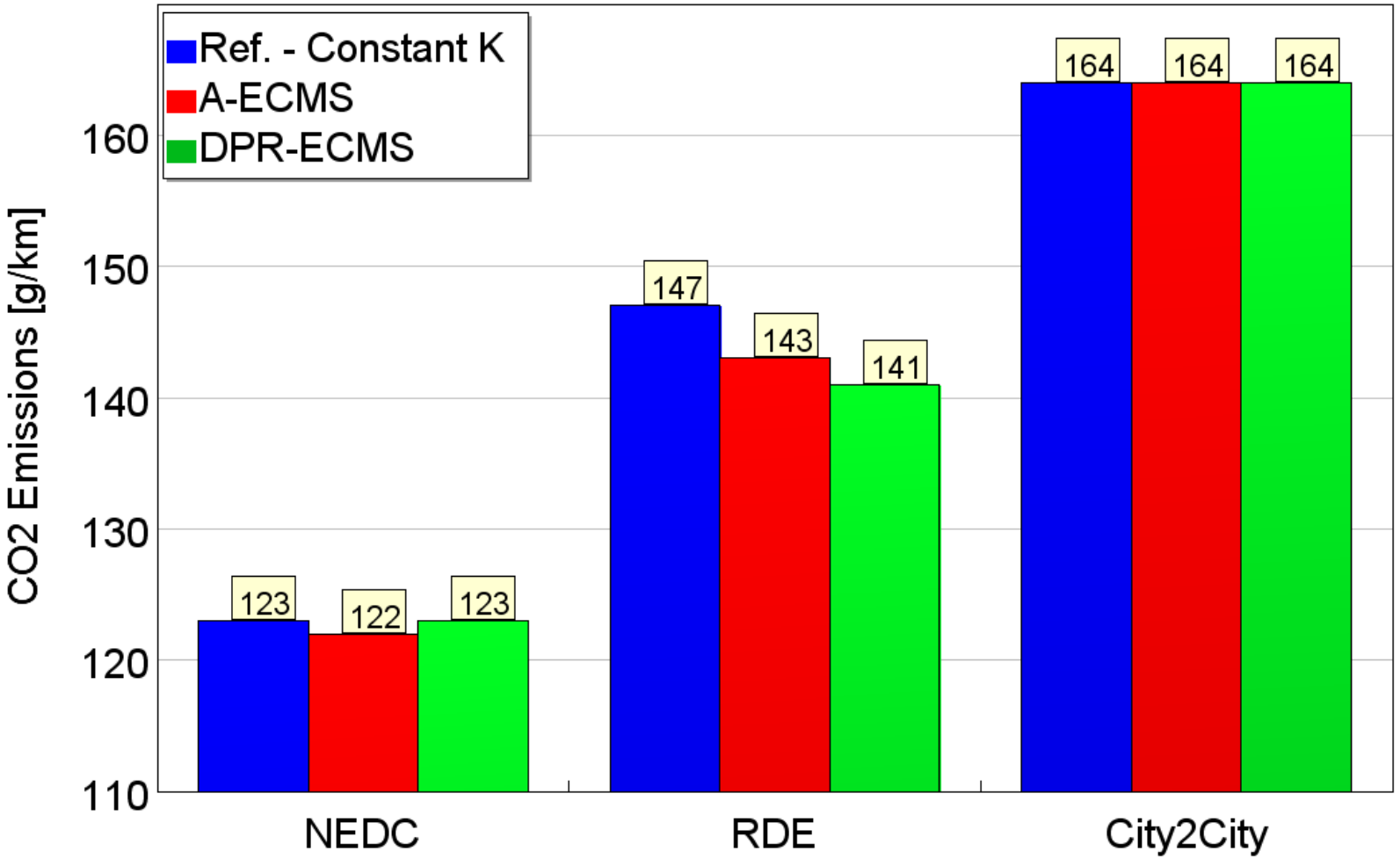
4. Results

- **Fuel consumption**

On **NEDC**, A-ECMS techniques achieves limited (**-1 gCO_2/km**) impact;

On **RDE**, A-ECMS reduced CO_2 emissions by **4 gCO2/km**, while DPR-ECMS by **6 gCO2/km** (but with larger SOC variation along the cycle)

On **City2City** the reference has same fuel consumption as A-ECMS and DPR-ECMS.



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5. Conclusions

An **improved Energy Management controller** was introduced into an existing GT-POWER vehicle model, representing a **P2 Mid-size SUV** with gasoline engine

Two **Auto-Adaptive Energy Management** controllers were developed and integrated in the vehicle model:
1. AECMS based on **SOC feedback** **2. Driving Pattern Recognition-ECMS**

The two Adaptive ECMS techniques have been tested along **Type Approval** and **RDE driving cycles** and compared with the reference vehicle featuring an ECMS with fixed K

Up to **6 gCO2/km** improvement have been achieved along a RDE driving cycle demonstrating the impact of EMS techniques that guarantee charge sustaining operation

This project showed how a **vehicle virtual plant** can be adopted for the **development** of **advanced Energy Management** controllers for Hybrid-Electric Vehicles

Future developments: improve charge sustainability of the DPR-ECMS (to reduce battery ageing), by expanding pattern recognition capabilities to RDE cycles, and develop a controller based on DPR and SOC feedback

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