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AI for tailored Energy Management of Hybrid Electric Vehicles

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Outline

- Project motivation and objectives
- Driver adaptive HEV controllers
- THEO : the AI agent development
- THEO: test case
- Conclusions

TRA Visions 2020 Young Researcher Competition

- Bi-yearly **research contest** aimed at university and technical institute **students all over Europe** (B.Sc., M. Sc, Ph.D.)
- 5 pillars/transport modes:

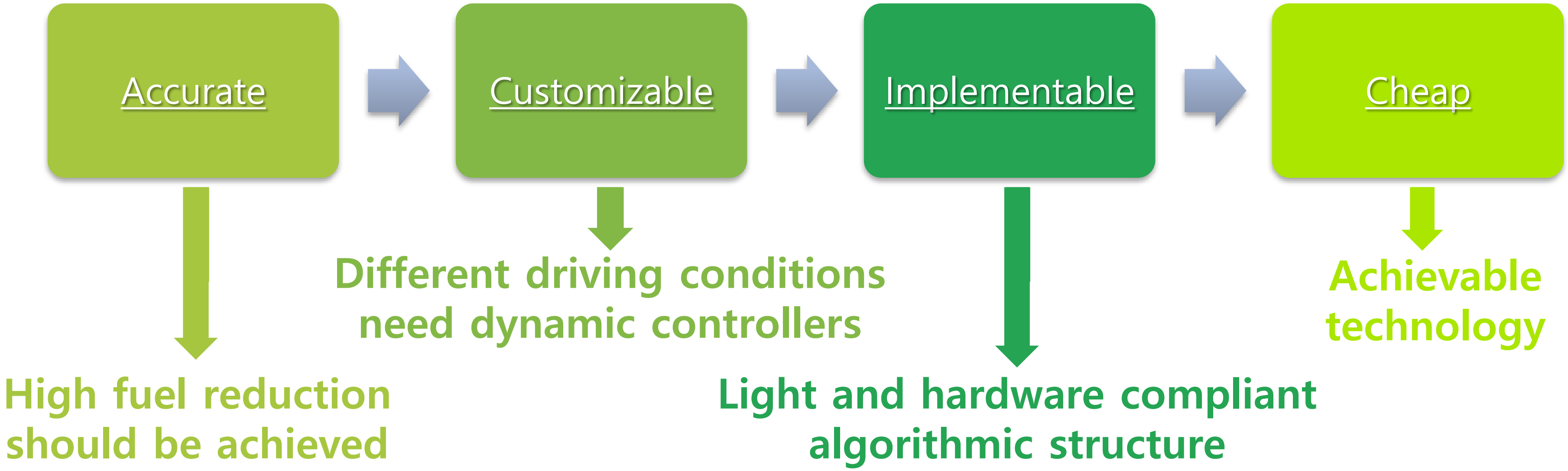
- **105** research projects submitted to the TRA Visions 2020 Young Researcher Competition

https://www.travisions.eu/TRAVisions/young_researcher_results_2020/

https://youtu.be/DwH1e8YqhOo

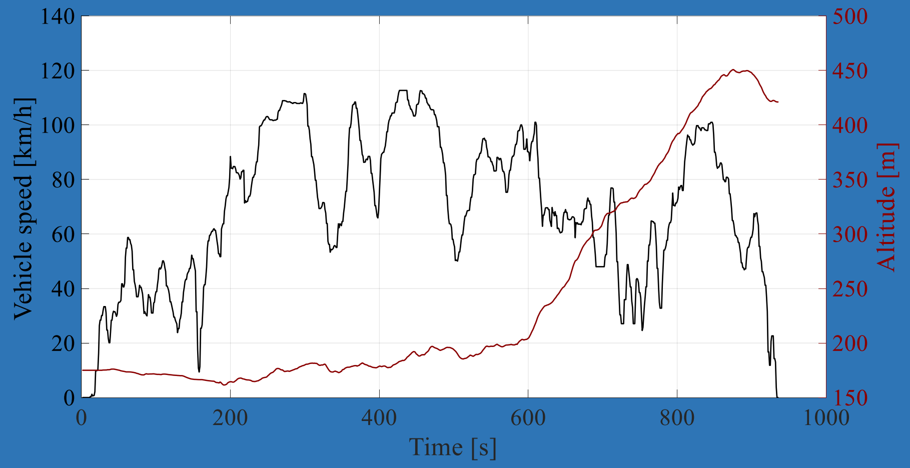
Project motivation and objectives

Hybrid vehicles can realistically be a shot-term solution to future on-road emission abatement targets **BUT** intelligent control stategies have to be developed.



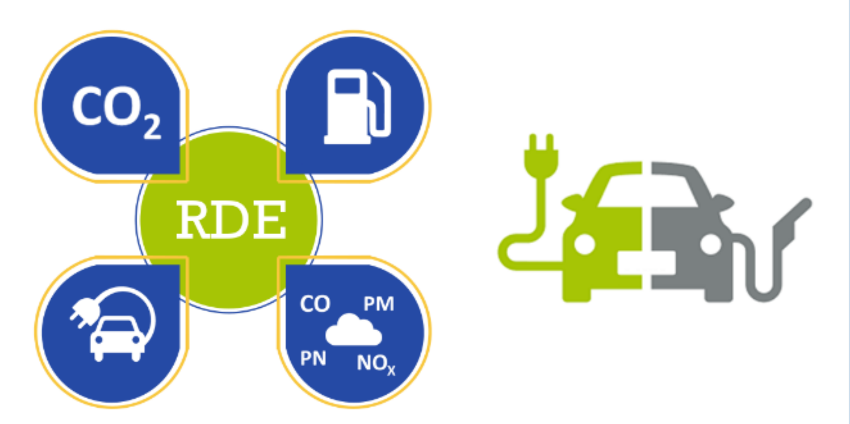
In near future (**2020-2030**), driver-based real driving emissions (RDE) might include fleet-wide CO2 limit.

Project motivation and objectives



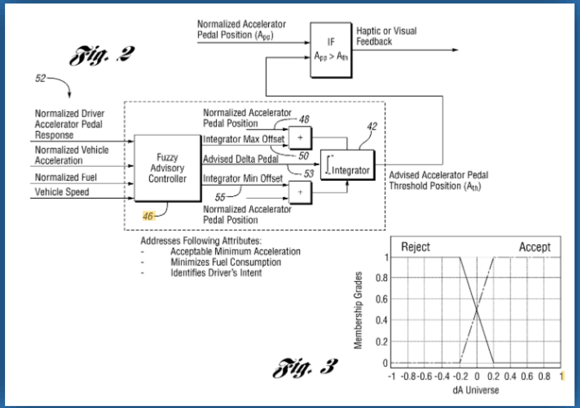
In RDE tests, several new contributions can be identified impacting on the on-road measured emissions, as example:

- the variety of driving conditions
- **the drive style**
- the road altitude
- traffic conditions
- wind



Driver adaptive HEV controllers

Examples from the state-of-art

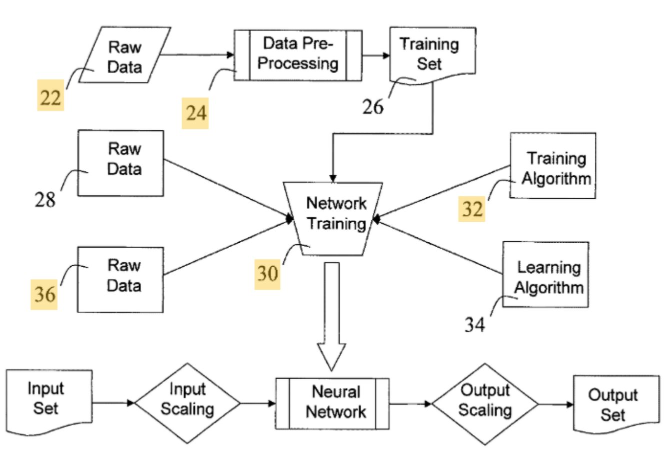


US Patent US9361272B2, 2016. "Adaptive real-time driver advisory control for a hybrid electric vehicle to achieve fuel economy".

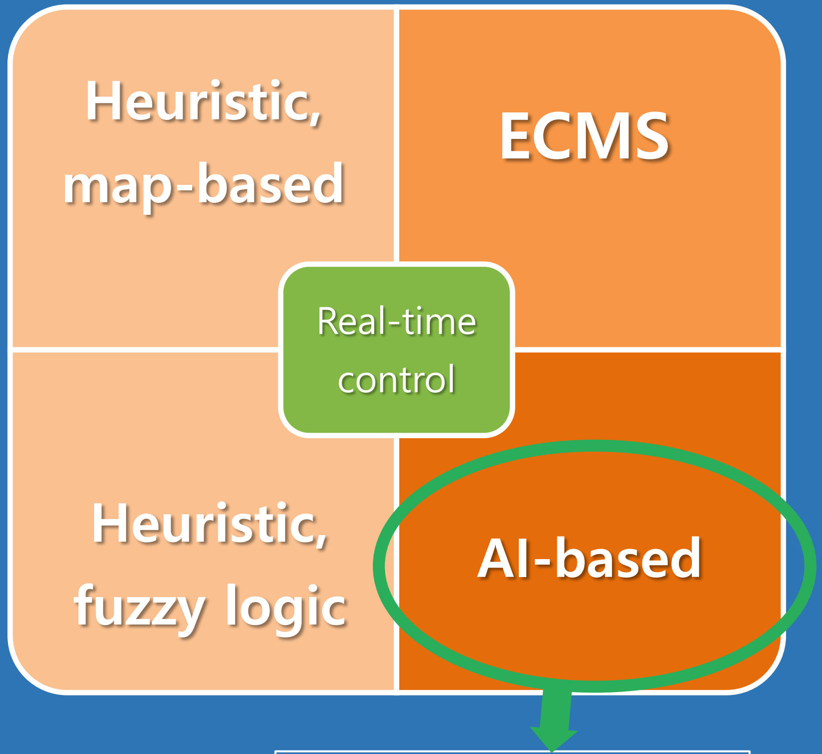
- The system hints the driver about a fuel economy-oriented acceleration pedal position (visual or haptic feedback);
- The driver needs to adapt its driving style to the implemented controller;
- The system cannot discriminate between different users driving the same vehicle.

US Patent US7954579B2, 2011. "Adaptive control strategy and method for optimizing hybrid electric vehicles".

- A Neural Network is used to learn from existing off-line HEV optimizers;
- It shows improved fuel economy with respect to rule-based controllers;
- The adaptive control relies only on standard driving missions;
- The user recognition process has not been considered.



Proposed solution



Selected algorithm → Development of Tailored Hybrid Emission Optimizer (THEO)

- HEV real-time controllers should **maximize** the HEV **fuel economy and pollutant emission performance**;
- Adequate **recognition of the driving style** related to the current driver of the vehicle should be considered;
- The control policies should **adapt to the characteristics of the journeys** generally performed by the same driver.

Recurrent Neural Networks

If you read this text, you get the **meaning** of **each word** by considering what you understood from the **previous words**.

Recurrent neural networks can address this task. Are they the answer to our problem?

Long-Short Term Memory (LSTM) Neural Networks are a particular type of RNN mainly designed to avoid long term dependency problem.

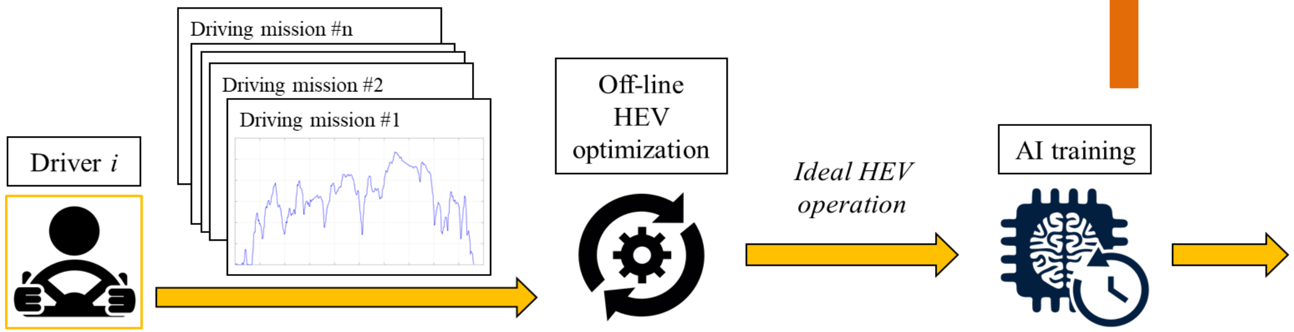
https://towardsdatascience.com/understanding-rnn-and-lstm-f7cdf6dfc14e
https://colah.github.io/posts/2015-08-Understanding-LSTMs/

THEO: the AI agent development

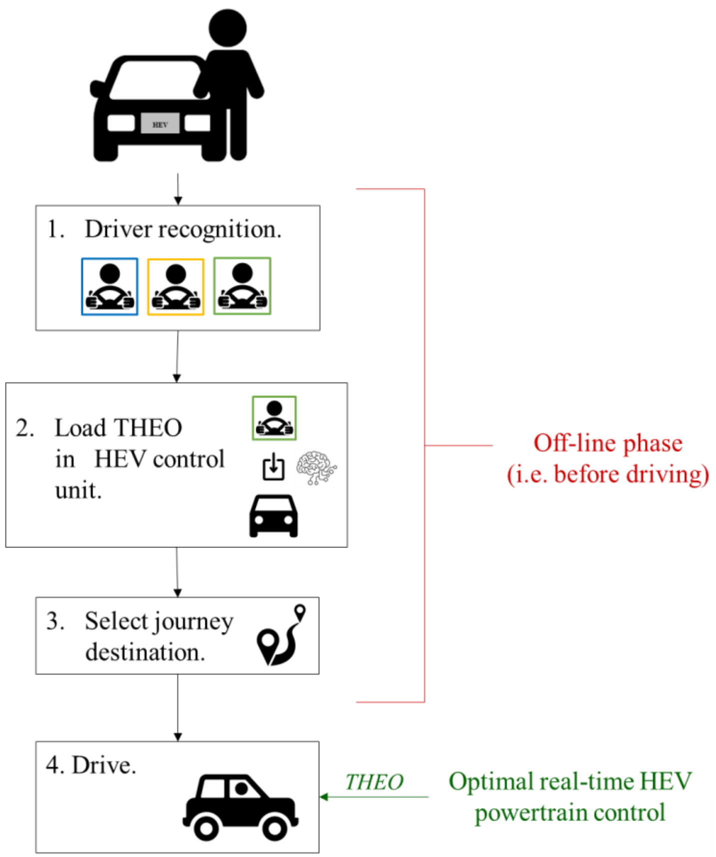
For each driver, a set of personal driving missions is collected

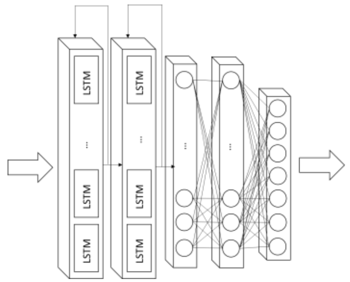
HEV off-line optimization is performed to define the ideal control policy (Dynamic Programming)

The AI agent is trained using the ideal off-line control policy



THEO ready for on-board usage

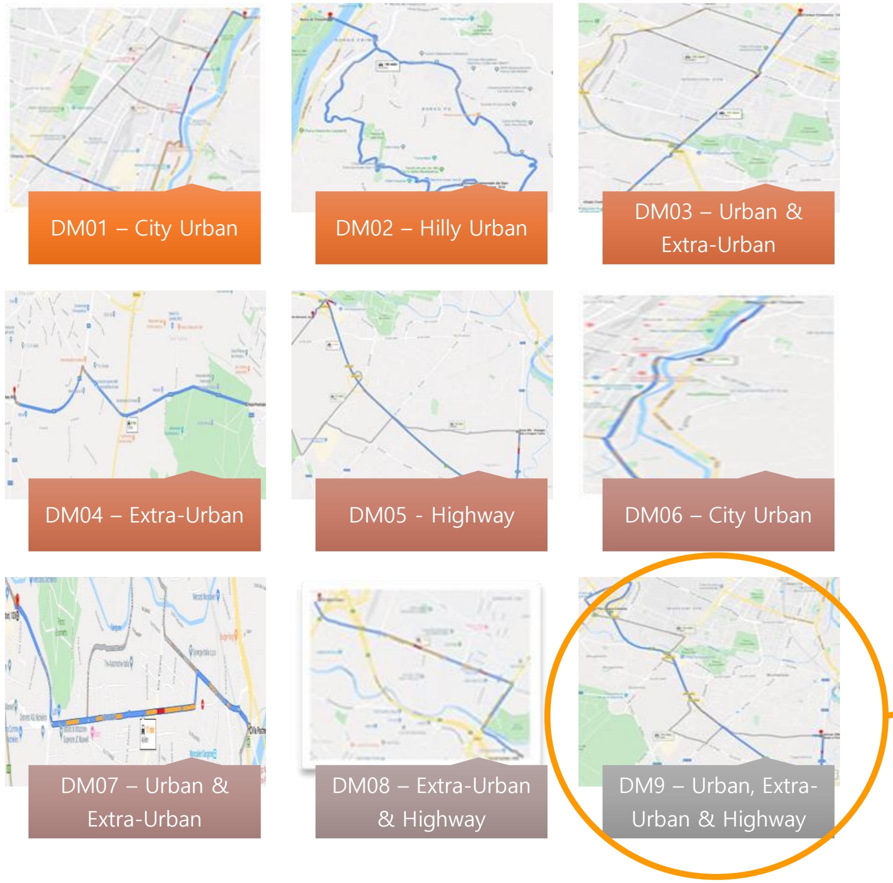


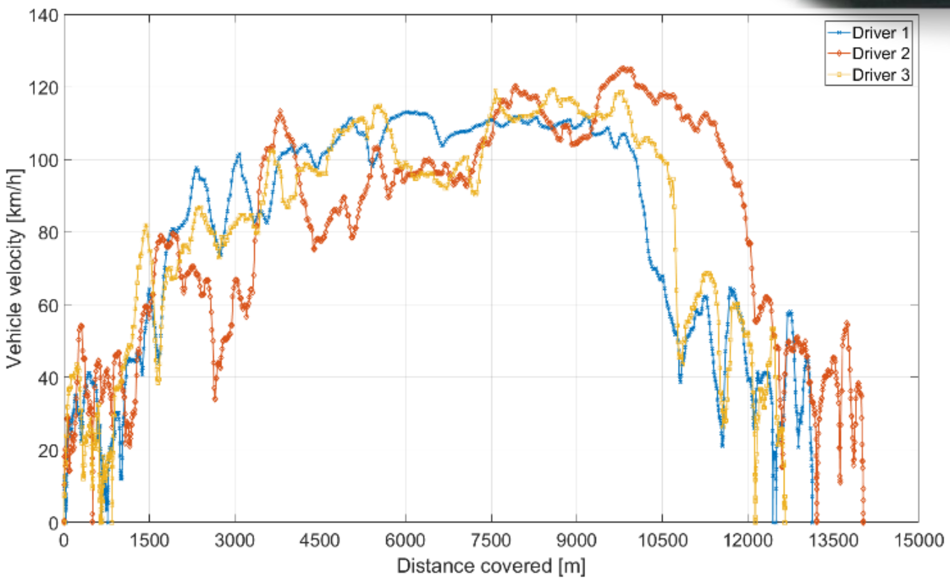


Once the **driver is recognized**, the customized version of **THEO is loaded** into the ECU.

Destination chosen, the drive can start under THEO's supervisory.

Experimental campaign:
3 Drivers × **9** Driving Missions × **1** vehicle × **1** acquisition system





Considered control strategies:
4 controllers (1 for conventional vehicle, 3 for HEV)

THEO: CO_2 emissions optimization

The **equivalent CO_2** values are estimated through both RBC and AI agent due to the necessity of evaluating the emissions at the same final SOC level guaranteed by DP.

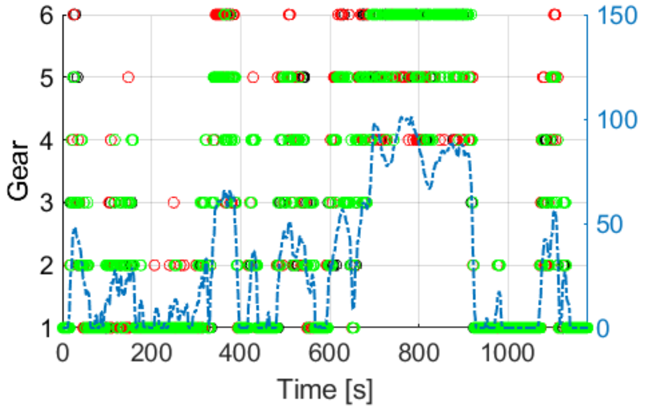
Driving mission	Driver	Equivalent CO_2 [g/km]			
		CVC*	DP**	RBC***	AI AGENT
DM07	*Driver 1*	200.06	151.19	176.75 *(ΔDP=+16,91%)*	150.45 *(ΔDP=-0.49%)*
	Driver 2	179.33	127.58	163.51 *(ΔDP=+28,16%)*	125.15 *(ΔDP=-1.9%)*
	Driver 3	178.77	116.62	145.50 *(ΔDP=+24.76%)*	116.71 *(ΔDP=+0.08%)*

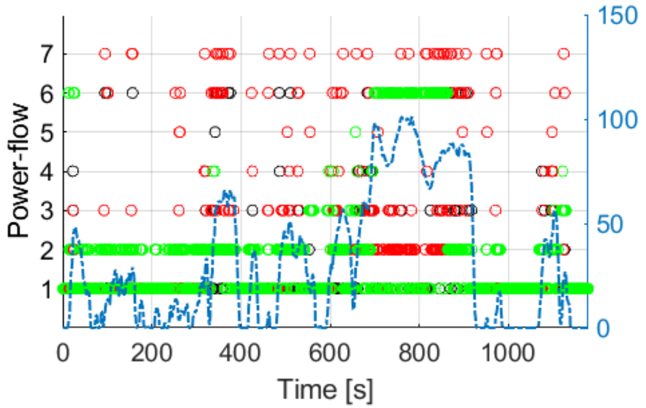
148.5 g/km < CO_2 < 151.5 g/km

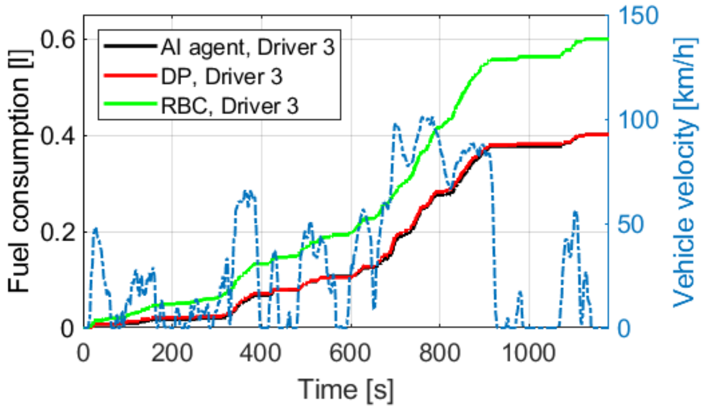
CO_2 < 148.5 g/km

CO_2 > 151.5 g/km

*CVC = Conventional Vehicle Control
**DP = Dynamic Programming
***RBC = Rule-Based Control







In the DM07, **matching with** optimal **DP** control actions:

- Gear: Similar RBC and AI agent behaviour;
- Power-flow: **RBC ~ 65.3%, AI agent ~ 88.4%.**

CO_2 reduction **(AI agent wrt RBC)** = **24.76%**

Conclusions

- Effective personal **driving pattern recognition** through AI agent
- Simulated real-world fuel consumption for an HEV application embedding THEO technology:
  - **gets close to optimal benchmark**;
  - reveals **compliant** to forecasted CO_2 regulations

Further steps

- Increase the amount of analysed driving data
- Test the technology through higher fidelity simulators
- Implementation and validation of AI agent on a real on-board HEV ECU
- Implementation and prototypation of a driver recognition system

Thanks for your attention