Plug in hybrid vehicles:

Insights on their potential to reduce CO_2 emissions in real-world operation

Jaime Suarez, Alessandro Tansini, Jelica Pavlovic, Giorgos Fontaras

European Commission, Joint Research Center

WCTRS Workshop "Decarbonizing the Transport Sector through Innovative Technologies", 20/09/2021

Part I: PHEVs and the CO_2 gap context

- CO_2 emissions in passenger cars
- PHEVs description
- Official certification procedures (WLTP)
- Fuel Consumption Gap

European Commission

CO_2 emissions in Transport sector

World Clima Context

- Paris Agreement: Need to achieve >55% reduction of GHG by 2030
- Transportation is responsible for 24% of CO2 emissions
- Passenger vehicles is the main source (45%)
- The average Type-Approval CO_2 emissions of a vehicle in 2019 were 122.4 g/km , still higher than 95 g/km set as target for 2020.

(“Tracking Transport 2020”, IEA, May 2020), *(EEA Data 2020)*

European Commission

PHEVs: How do they work?

PHEV

Can operate in 2 modes:

Electric mode

- Uses <u>electric</u> engine
- Propelled from a HV batt.
- Recharge battery from e-**grid**
- (Similar performance to EV)

ICE mode

- Uses <u>combustion</u> engine
- Propelled from burning fuel
- Conventional fuel stations
- (Similar performance to full hybrid)

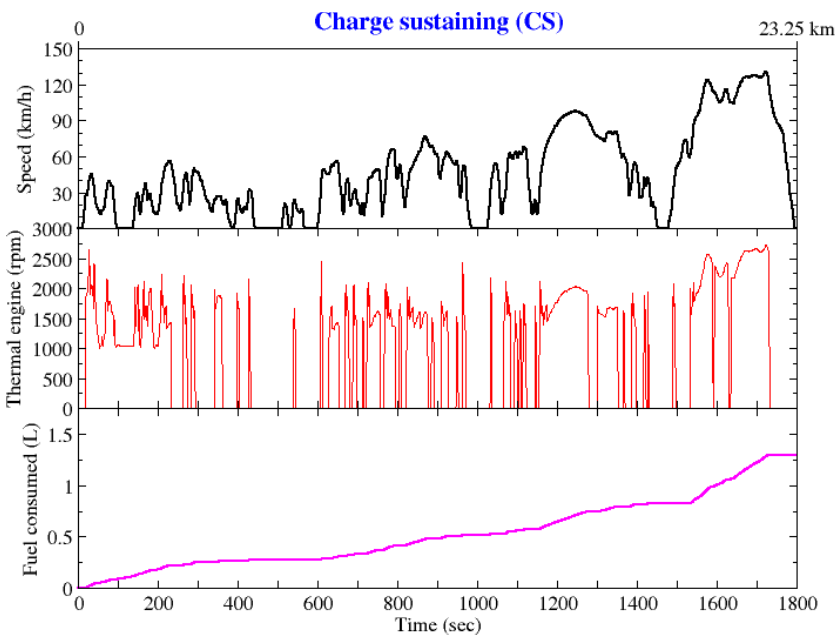
✓ Zero-carbon emissions
✗ Low distance-range

✗ High CO_2 emissions
✓ Long distance-range

WLTP speed cycles in PHEVs

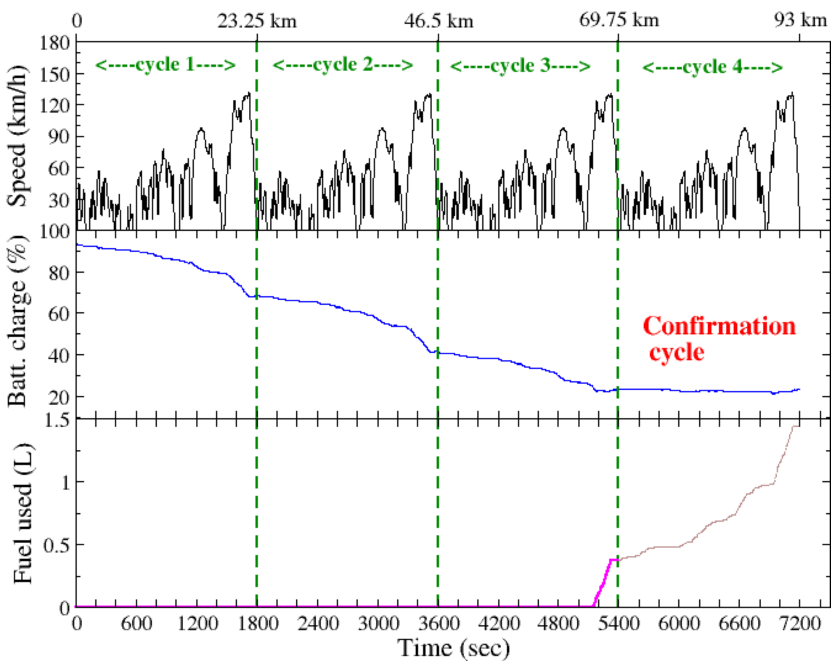
Charge Sustaining

Starts from batt. depleted



Charge Depleting

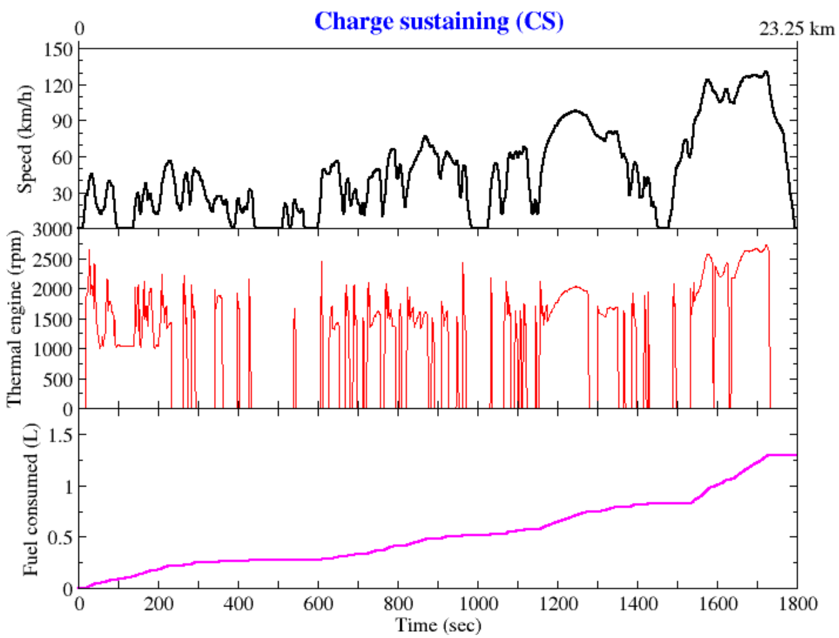
Starts from battery 100%



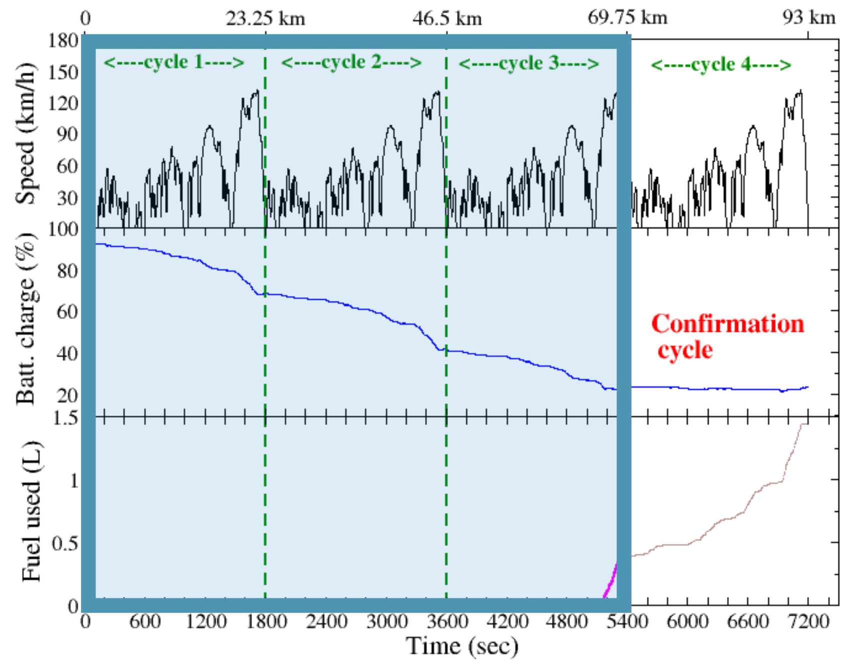
European Commission

WLTP speed cycles in PHEVs

Charge Sustaining



Charge Depleting



European Commission

FC Gap between RW and TA

- CO_2 emissions in ICE directly related to Fuel Consumption of hydrocarbon fuels. (More FC, more CO_2)
- According to TA, a typical PHEV can reduce CO_2 to less than 1/3rd of conventional ICE vehicle (*e.g. 4.1L/100km => 1L/100km*)
- There is a **gap of ~40%** between the official FC figures and actual fuel use for the whole vehicle fleet (FC gap)
- The divergences for PHEVs can be even broader, **up to 200%**
- The key point is the ratio CD / CS in real world use

FC Gap between RW and TA

What causes this gap? Possible causes:

1. **Distances** travelled different from predicted by UF-WLTP
2. **Speed pattern in real life** different from WLTP cycle
3. Assumption in WLTP of **100% initial battery charge**
4. Use of AC (and other **electrical consumers**) [Not addressed here…]

European Commission

Part II:
Performance of PHEVs in real-world

- PHEVs used in this study
- Analysis of trips and FC
- Conclusions on nature of the Fuel Consumption Gap

PHEVs used in this study

Case 1	Case 2
Mass: 1600 kg	*Mass:* 1935 kg
Max. Power: 77.2 kW /44.50 kW	*Max. Power:* 97kw /69kw
PWR = 0.05 [kW/kg]	*PWR* = 0.05 [kW/kg]
Fuel: Gasoline	*Fuel:* Gasoline
e-range (EAER): 49 km	*e-range (EAER):* 49 km
FC: **1.4 L/100km** (*CO_2* 31 g/km)	*FC:* **2.1 L/100km** (*CO_2* 46 g/km)
Year: 2021	Year: 2021

OBFCM data from PHEVs

Reg. EU2017/1151: **OBFCM** (on-board Fuel Consumption Monitoring) is mandatory in vehicles since year 2021

5.2. *For OVC-HEVs:*

(a) Total fuel consumed (lifetime) (litres);

(b) total fuel consumed in charge depleting operation (lifetime) (litres);

(c) total fuel consumed in driver-selectable charge increasing operation (lifetime) (litres);

(d) total distance travelled (lifetime) (kilometres);

(e) total distance travelled in charge depleting operation with engine off (lifetime) (kilometres);

(f) total distance travelled in charge depleting operation with engine running (lifetime) (kilometres);

(g) total distance travelled in driver-selectable charge increasing operation (lifetime) (kilometres);

(h) engine fuel rate (grams/second);

(i) engine fuel rate (litres/hour);

(j) vehicle fuel rate (grams/second);

(k) vehicle speed (kilometres/hour);

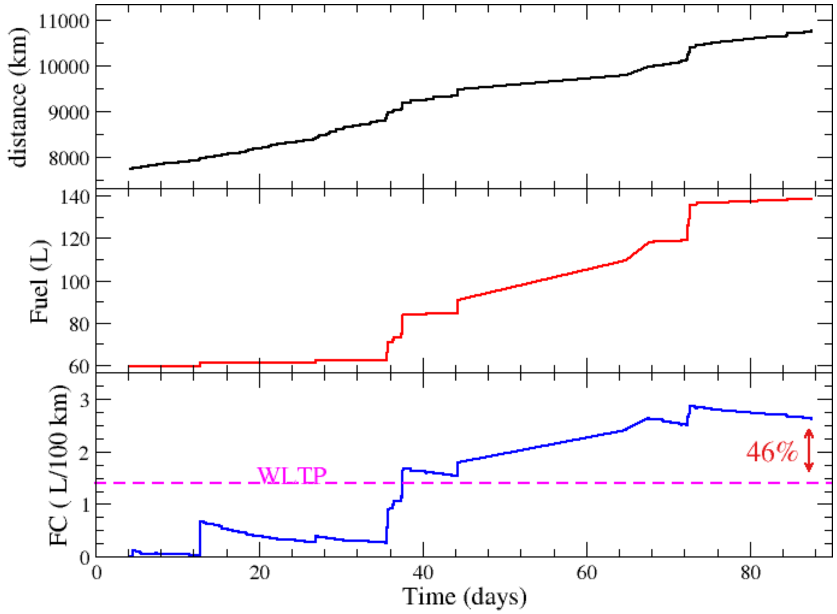
(l) total grid energy into the battery (lifetime) (kWh).

- ✓ **Total distance travelled**
- ✓ **Total fuel consumed**
- ✓ **Total grid energy into the battery**

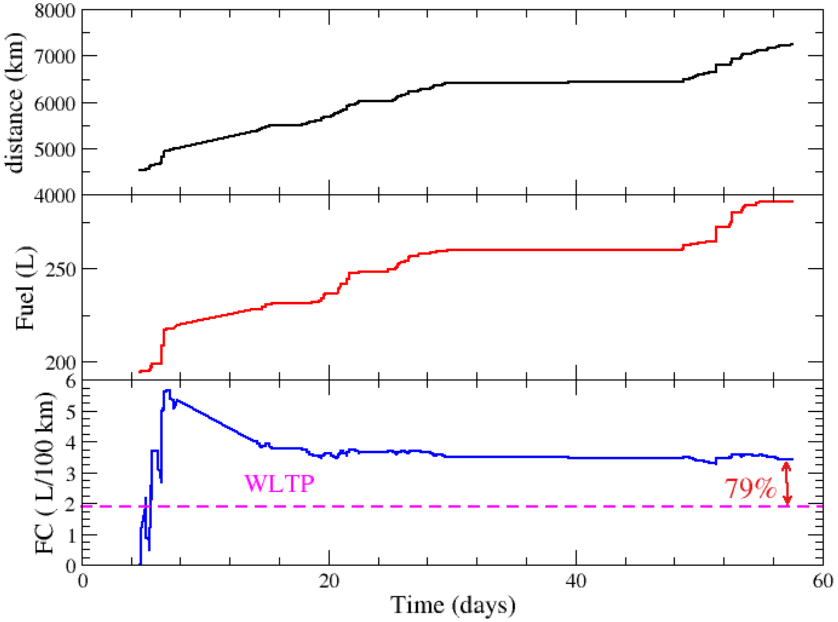
European Commission

Real consumption *vs.* official values

Case 1



Case 2

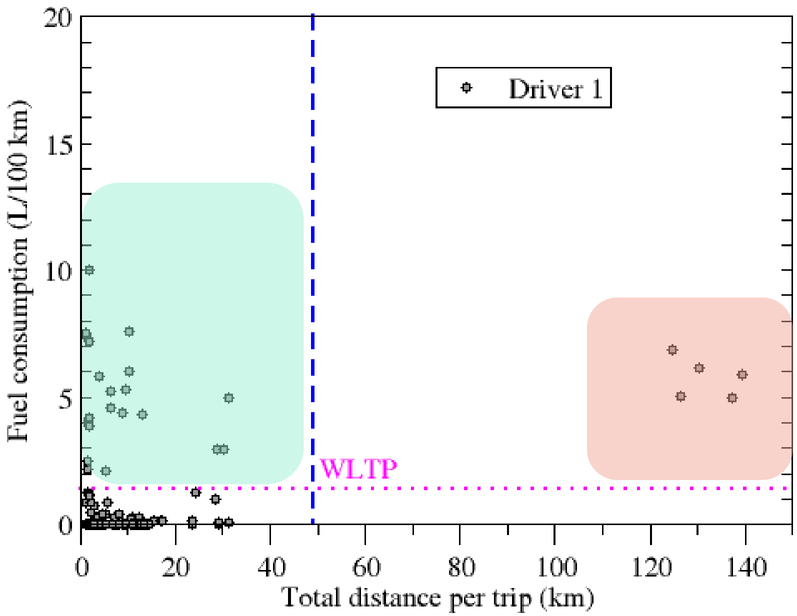


FC **increases 46% and 79%** with respect to official values

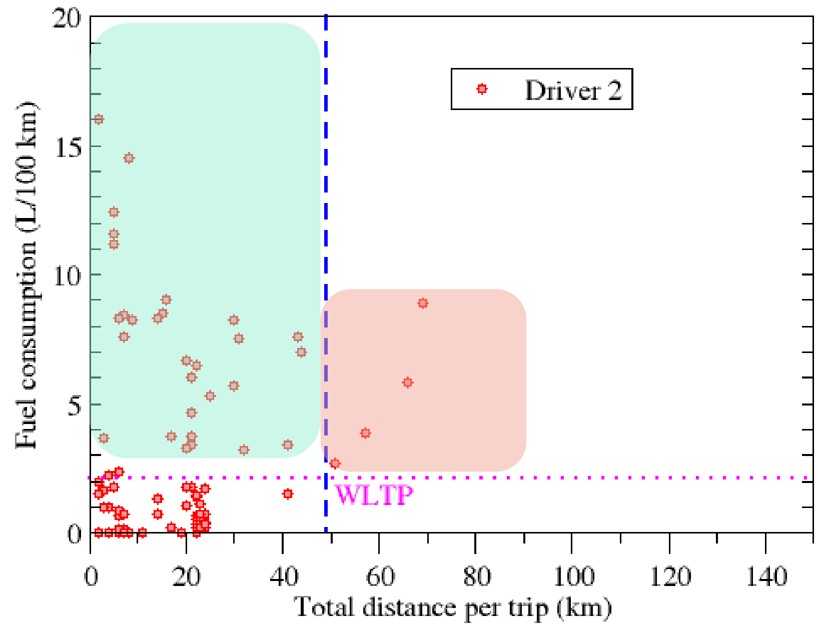
European Commission

Trips as function of Fuel Consumption

Case 1



Case 2

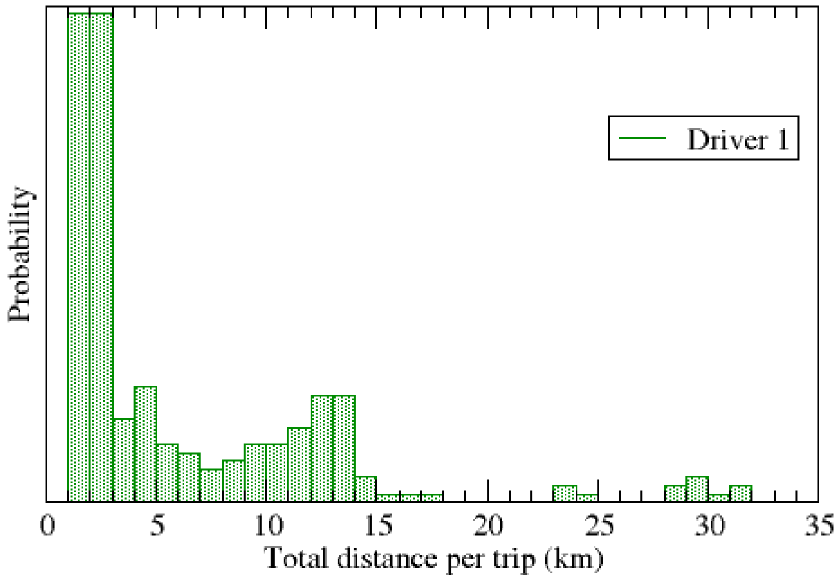


Trips above e-range show FC > WLTP value

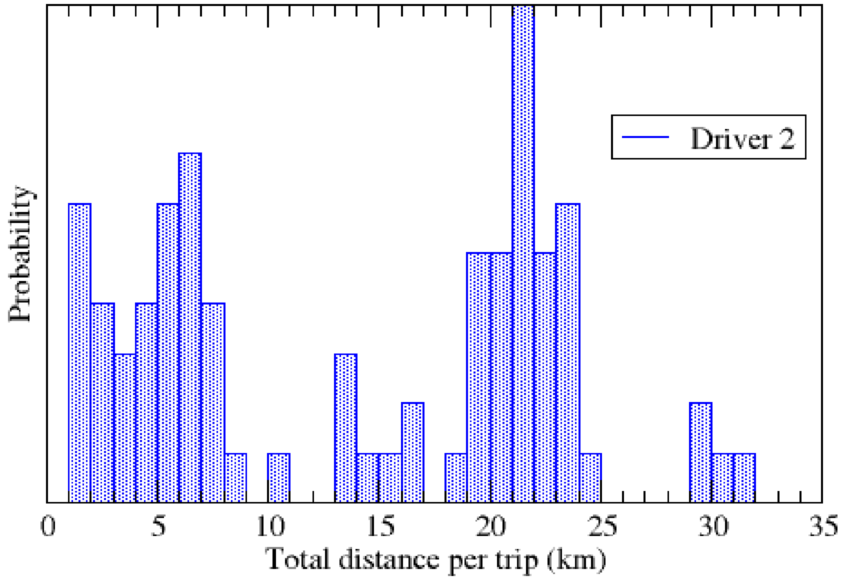
But FC > WLTP can take place even at shorter distances!

1) Analysis of distances travelled

Case 1



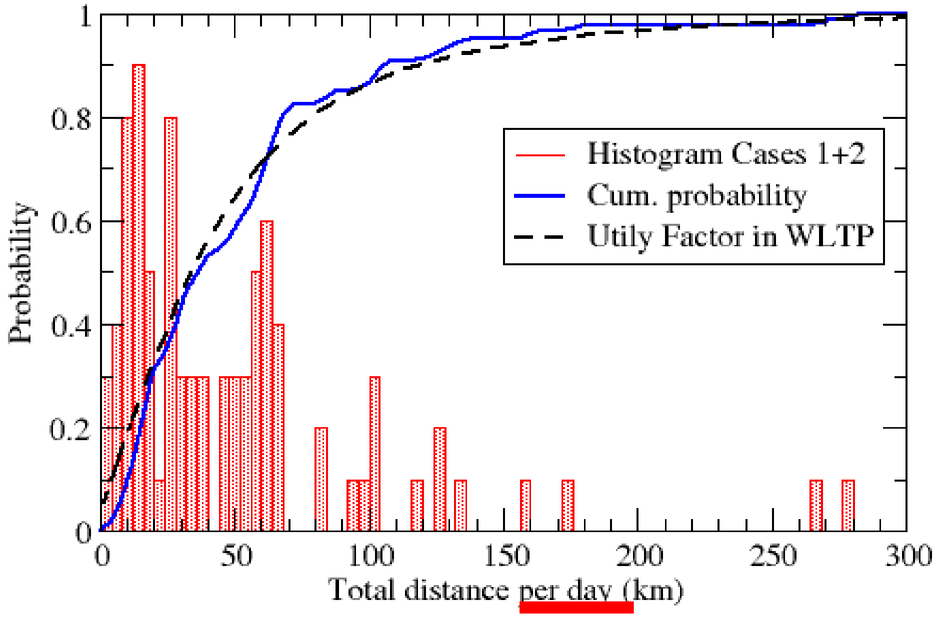
Case 2



Short trips for Case 1, Longer trips in Case 2

European Commission

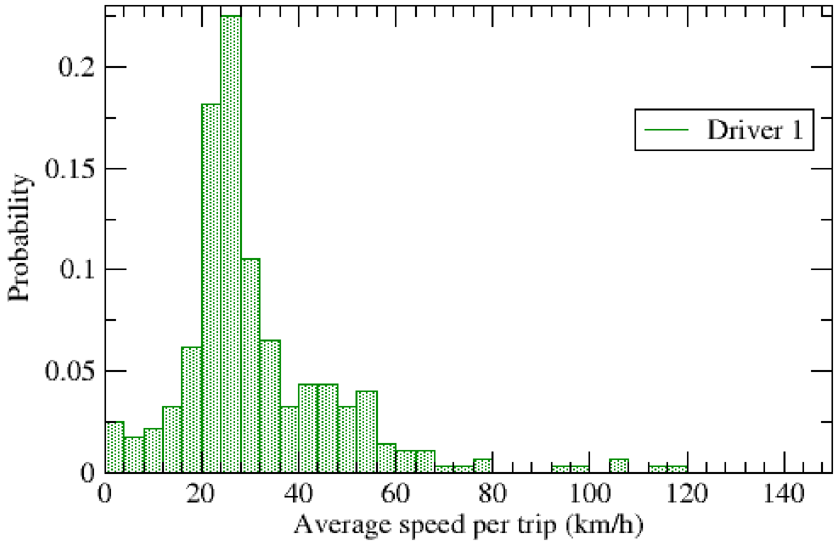
1) Analysis of distances travelled (ii)



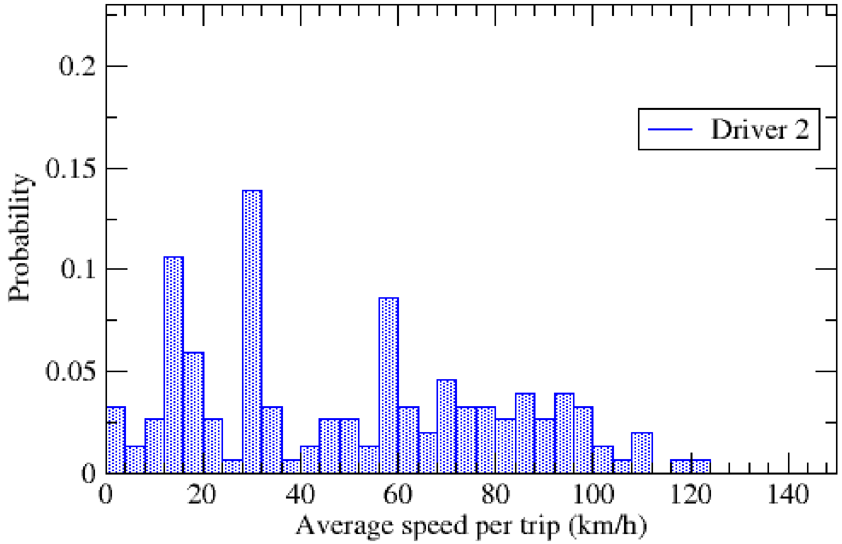
- Excellent agreement between distance travelled **per day** of PHEV users and the general mobility fit (mostly conventional cars)
- Very few trips > 100 km
- Most of the trips < 50km

2) Analysis of average speeds

Case 1



Case 2

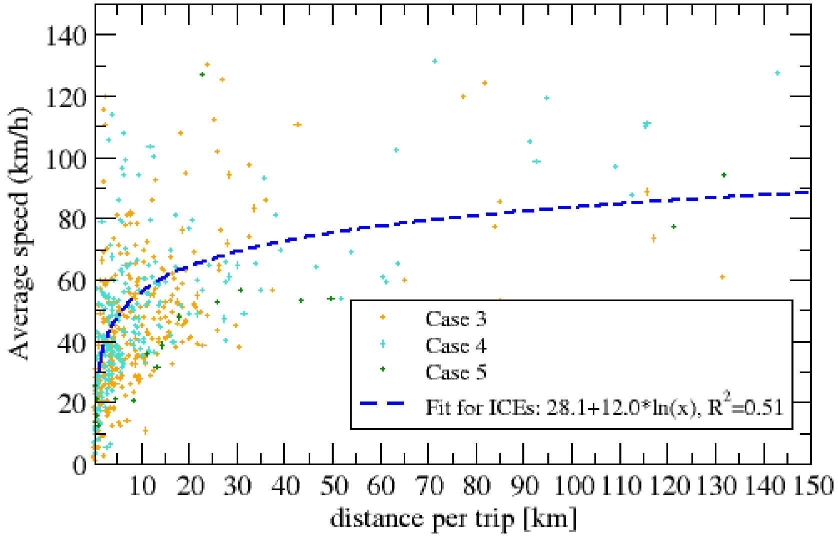


Case 2 shows higher speeds than Case 1

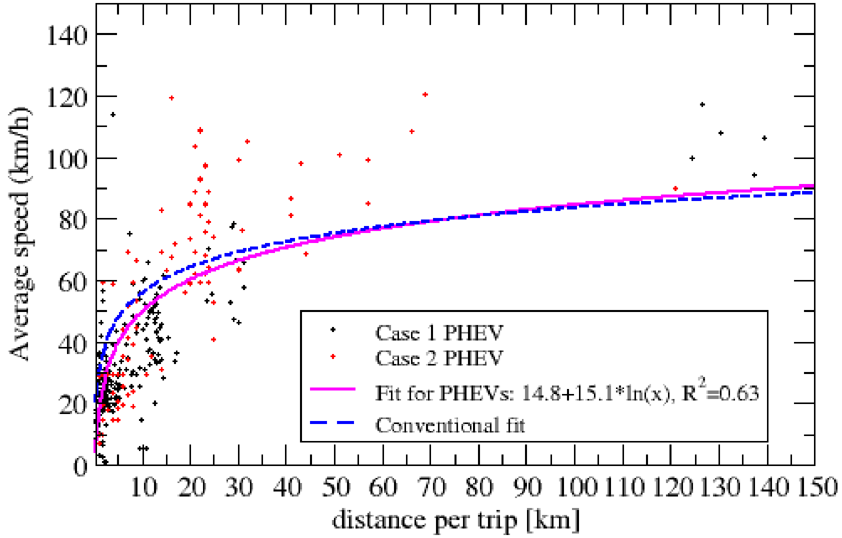
European Commission

2) Analysis of average speeds (ii)

Conventional

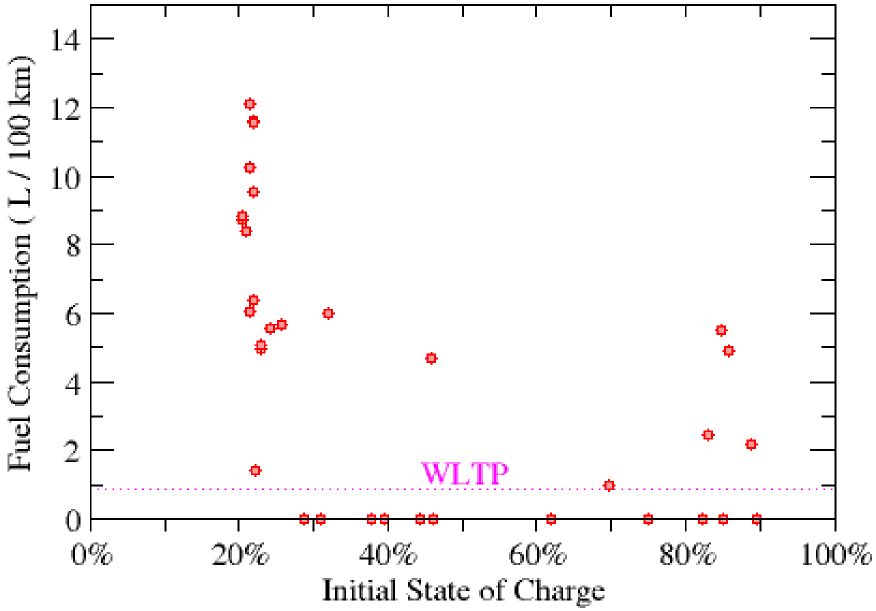


PHEVs



Similar logarithmic fitting for conventional cars and PHEV drivers

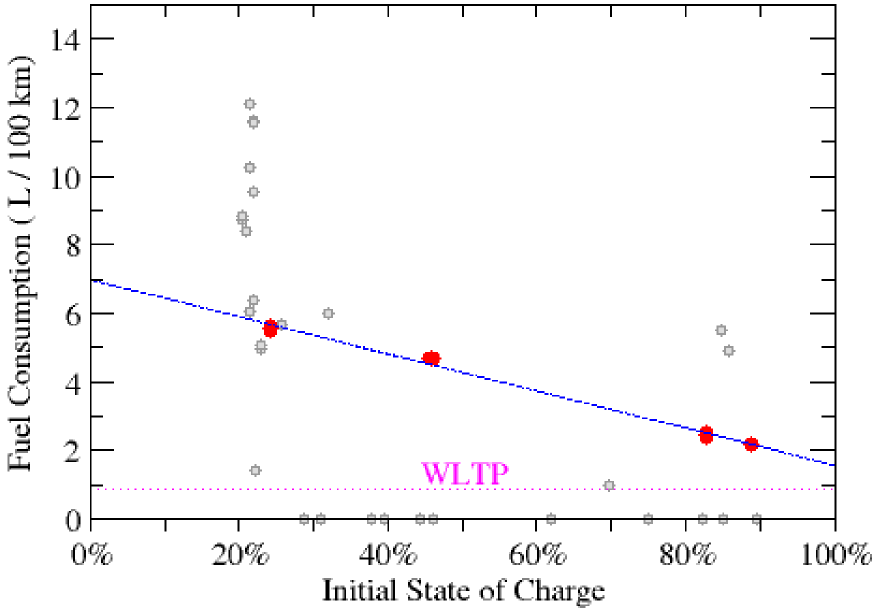
3) Impact of a depleted battery



From recent driving campaign on PHEV with **e-range: 69km**, **FC: 0.9 L/100km**

- Preliminary evidence shows a clear decreasing trend in FC with increasing initial battery charge

3) Impact of a depleted battery

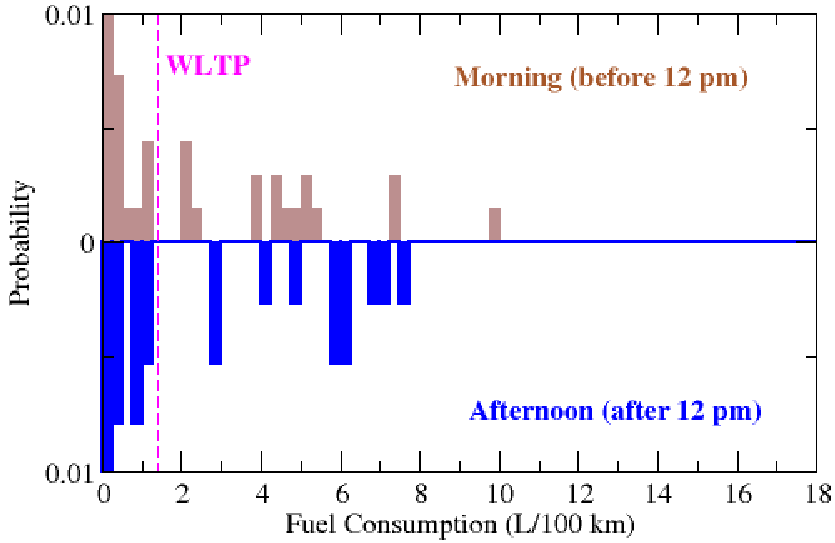


From recent driving campaign on PHEV with **e-range: 69km**, **FC: 0.9 L/100km**

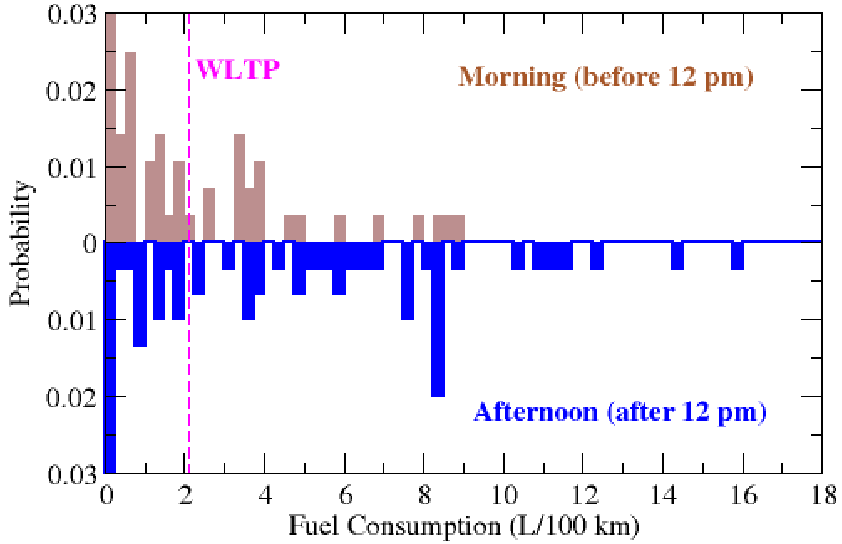
- Preliminary evidence shows a clear decreasing trend in FC with increasing initial battery charge
- Selecting trips between [40km,60km] yields an even more clear (linear?) trend

3) Impact of a depleted battery (ii)

Case 1



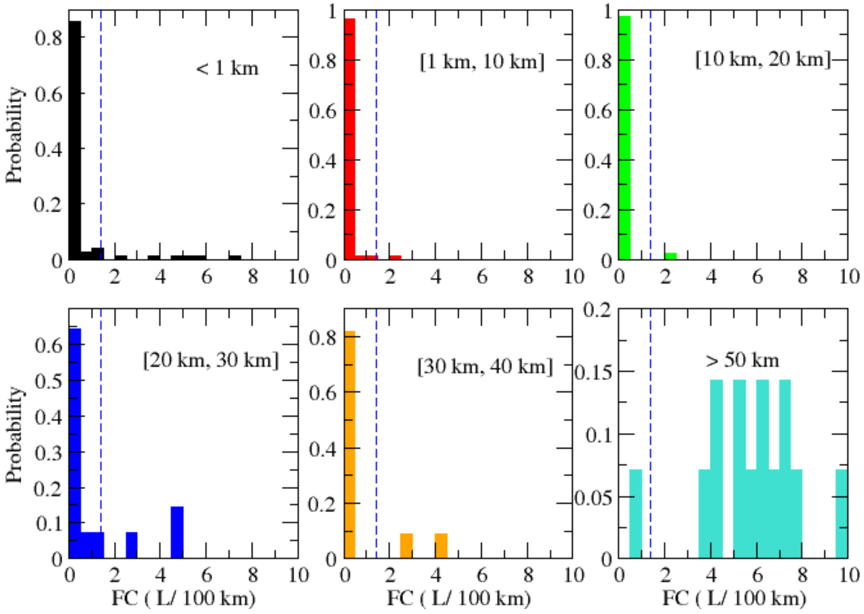
Case 2



Clear trend towards higher consumption in afternoon (depleted battery?)

3) Impact of a depleted battery (iii)

Filter the trips according to the previous **distance driven** after battery charging



Case 1

For cases < 20 km, most of the FC is very low (Battery has been recently charged)

For cases > 20 km, considerable number of high-FC events (Battery partially depleted).

For > 50km most of events are above official WLTP data (Battery completely depleted)

Conclusions…

- PHEVs are promising solutions for reducing CO_2 in road transport
- But their performance in real-world (RW) is not optimal (FC, CO_2).
- Gaps between RW and official TA values can reach up to 200%.
- We analysed possible factors involved in this gap:
  - Utility Factor defined in WLTP seems to fit with use of PHEVs
  - Reasonable WLTP assumption of driving speeds
  - Assumption of **100% initial SOC** is questionable.
- Charging habits from the driver must be taken into account. FC increases linearly when SOC ≠ 100% (assumed in WLTP)

…and future work

- Understand the impact of **electric consumers** (AC, heater,…)
- Quantify differences between **Summer / Winter** consumption
- Evaluate impact of specific **driving styles**
- Employ **OBFCM** data available since 2021 from larger fleet of vehicles to improve statistics

Keep in touch

EU Science Hub: ec.europa.eu/jrc

@EU_ScienceHub

EU Science Hub – Joint Research Centre

EU Science, Research and Innovation

EU Science Hub

Thank you

Slide 4: Vehicle icons, source: www.flaticon.com

EU countries