Fraunhofer ISI

Fraunhofer-Institut für System- und Innovationsforschung ISI

EVS 35 – Oslo, Norway, 2022

Real-world usage of plug-in hybrid electric vehicles

Dr. Patrick Plötz

Summary: Analysis of 100,000 PHEVs confirms high deviation fro official fuel efficiency and CO_2 values.

2020 study

Background and study

- Plug-in hybrid electric vehicles (PHEVs) use electricity as well as conventional fuel for driving.
- They offer environmental benefits if they are mainly driven on electricity.
- The present study is the first large international and systematic study of real-world usage of PHEVs.

Findings

- PHEV **fuel consumption & tail-pipe CO_2 emissions are two to four times higher than type-approval**.
- Real-world **share of electric driving** of PHEVs **is about half the share in type-approval** values.
- PHEVs are **not charged every day**.
- PHEVs show **high annual mileage and many long-distance trips**.
- PHEVs **electrify many kilometers** per year.
- **Decrease engine power and increase range** to improve real-world fuel consumption & CO_2 emissions of PHEVs.

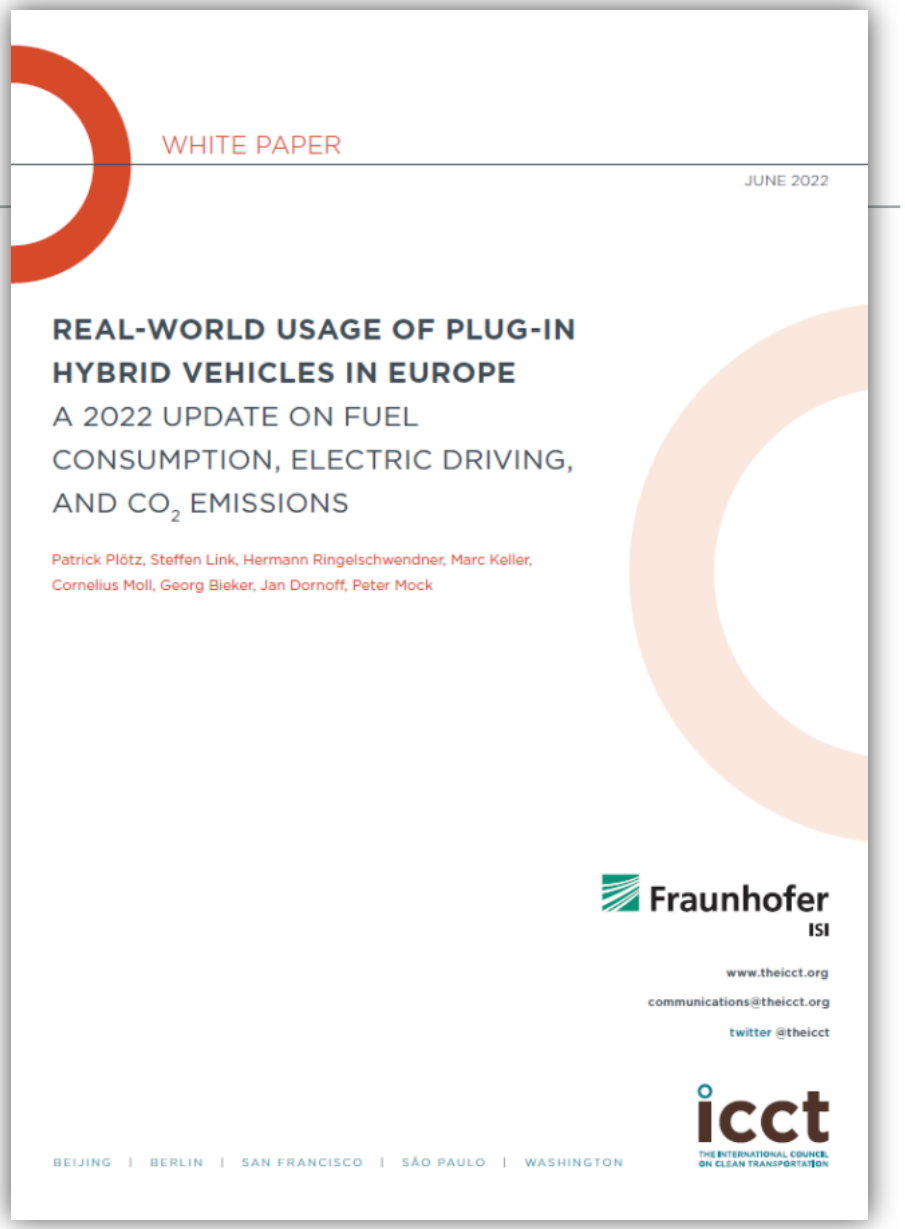
Source: ICCT/Plötz et al. (2020): Real-world usage of plug-in hybrid electric vehicles: Fuel consumption, electric driving, and CO2 emissions. ICCT White paper. Sept. 2020. https://theicct.org/publications/phev-real-world-usage-sept2020

Fraunhofer ISI

New PHEV study

- Update of 2020 study with new data
- Focus on Europe and WLTP certified vehicles
- Collection of new primary data
- Data collection completed, analysis ongoing
- Publication planned for April / May 2022

https://theicct.org/publication/real-world-phev-use-jun22/



Fraunhofer ISI

Collection of PHEV real-world fuel consumption data

- Collection of primary fuel consumption data from a large sample of PHEV in Europe
- No direct measurement of single vehicles but collection of data from large number of vehicles from
  - online fuel consumption diaries
  - company car fuel card data
  - online surveys

- Only results with new primary data are shown, no data from 2020 study used

Observed variables:

- long-term average fuel consumption in litres/100km
- annual mileage
- Make, model, variant and construction year
- Official test procedure fuel consumption $FC_{combined}$ (NEDC or WLTP assigned from make, model, variant, and year)

Derived variables:

- deviation from test values: FC_{real} / $FC_{combined}$
- Electric drive share (e-km / total-km) (UF_{real})

Fraunhofer ISI

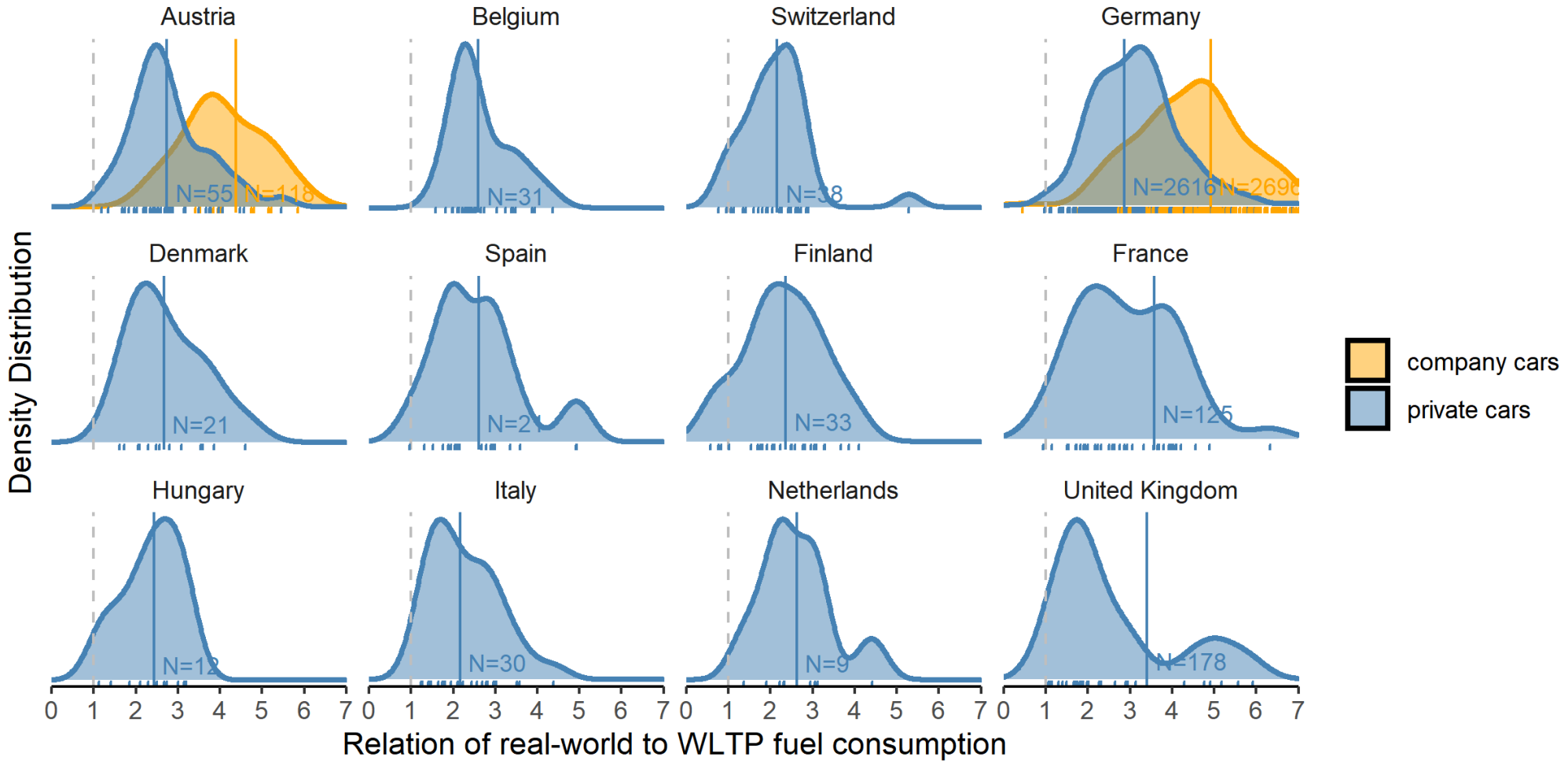
Overview data collection: New primary data from almost 9,000 individual PHEV from all of Europe covering 2013 – 2021.

- **PHEV from Germany**
  - online fuel log diary Spritmonitor.de (N = 2,666)
  - DLR survey for Germany (N = 1,531)
  - from 13 companies in Germany (N = 2,924)
- **Rest of Europe**
  - *Private*: non-German Spritmonitor users and other online fuel log sources (carbuyer.co.uk, honest-john, fiche-auto, MILE21)(N = 1,609;
    UK 370; FR 261; AT 226; 50 – 100 in NL, CH, FI, HU, IT, BE, DK)
  - *Company cars*: N = 119 in AT + 4 from survey
- **PHEV model years** 2012–2021, mainly 2017–2021

PHEV in sample	Germany	Rest of Europe	Total
Private	4,199	1,609	5,808
Company car	2,924	123	3,047
Total	**7,123**	**1,732**	**8,855**

PHEV in sample	Only NEDC	Only WLTP	NEDC & WLTP
Private	2,536	25	3,242
Company car	229	0	2,817
Total	**2,765**	**25**	**6,059**

Real-world fuel consumption is 2.5-3 times higher than WLTP for private & 4-5 times higher for company cars.



Fraunhofer ISI

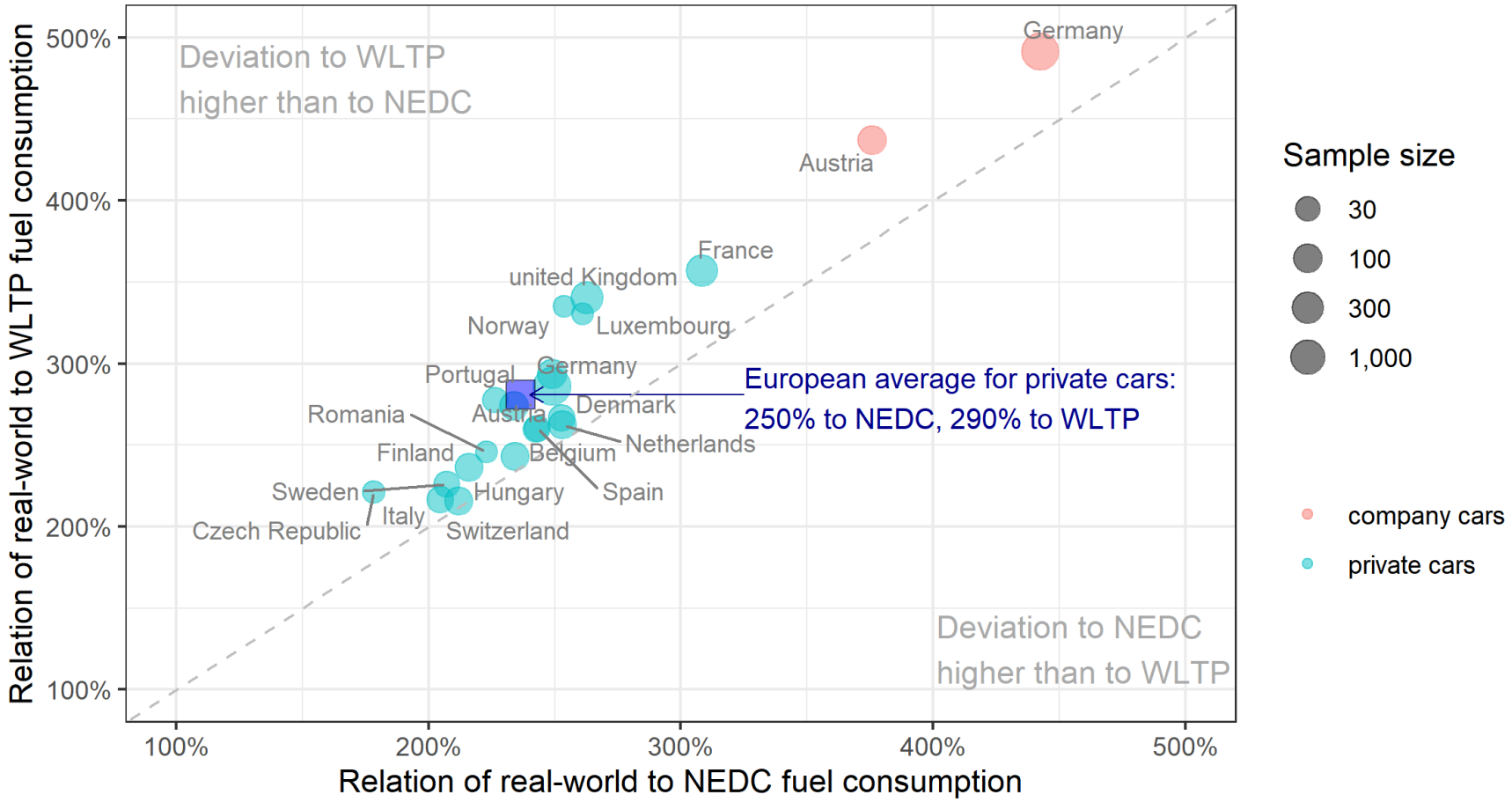
Deviation to real-world is larger for WLTP than NEDC in almost all countries.

Weighted mean deviation for **private vehicles**

- **240–260 % from NEDC for → ca. 2.5 times higher**
- **270–310 % from WLTP → almost 3 times higher**

Weighted mean deviation for **company cars**

- **420–460 % from NEDC → almost 4.5 times higher**
- **455–520 % from WLTP → almost 5 times higher**

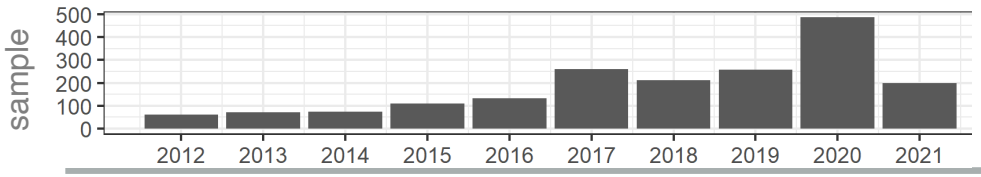


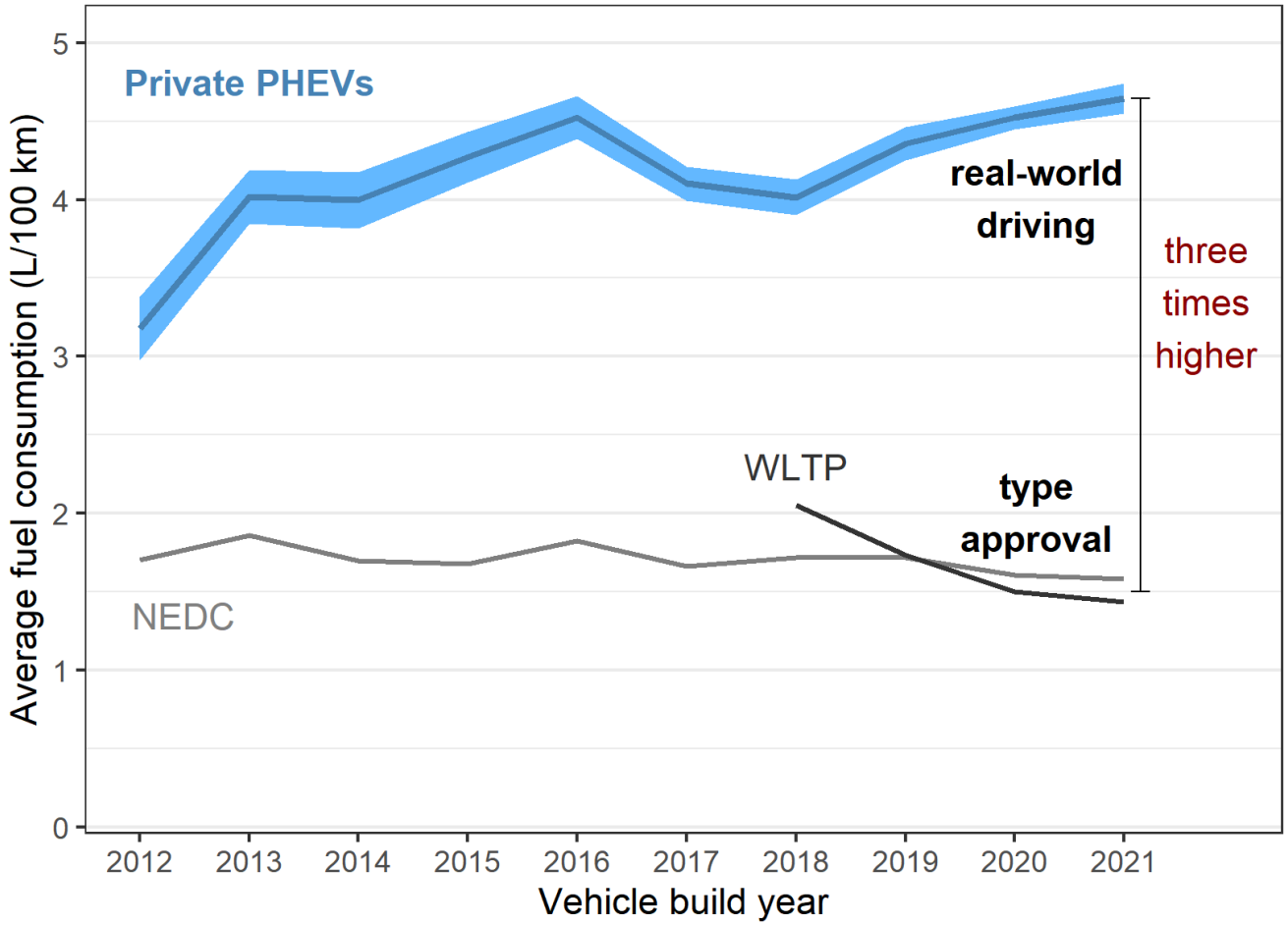
Deviation is 220–240 % from NEDC for only NEDC certified private vehicles → ca. 2 times higher
Deviation is 360–410 % from NEDC for only NEDC certified company car vehicles → almost 4 times higher

Fraunhofer ISI

Real-world fuel consumption of private PHEV increased over time and difference to test cycle value grows.

- Shown is the mean (± one standard error) fuel consumption of private PHEV in the sample by construction year
- The sample mean NEDC fuel consumption is shown as dashed line (WLTP mean dashed-dotted)
- Deviation between test-cycle and actual fuel consumption is increasing for private PHEVs and high for company cars

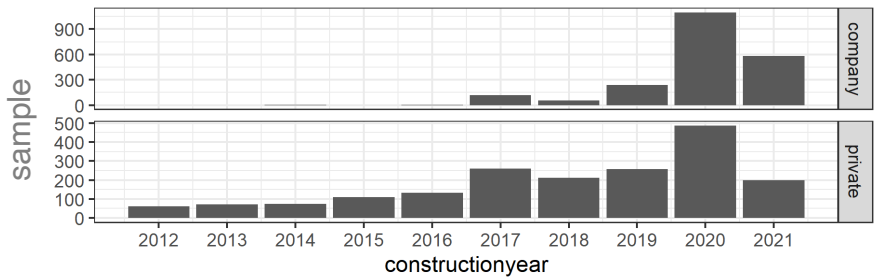


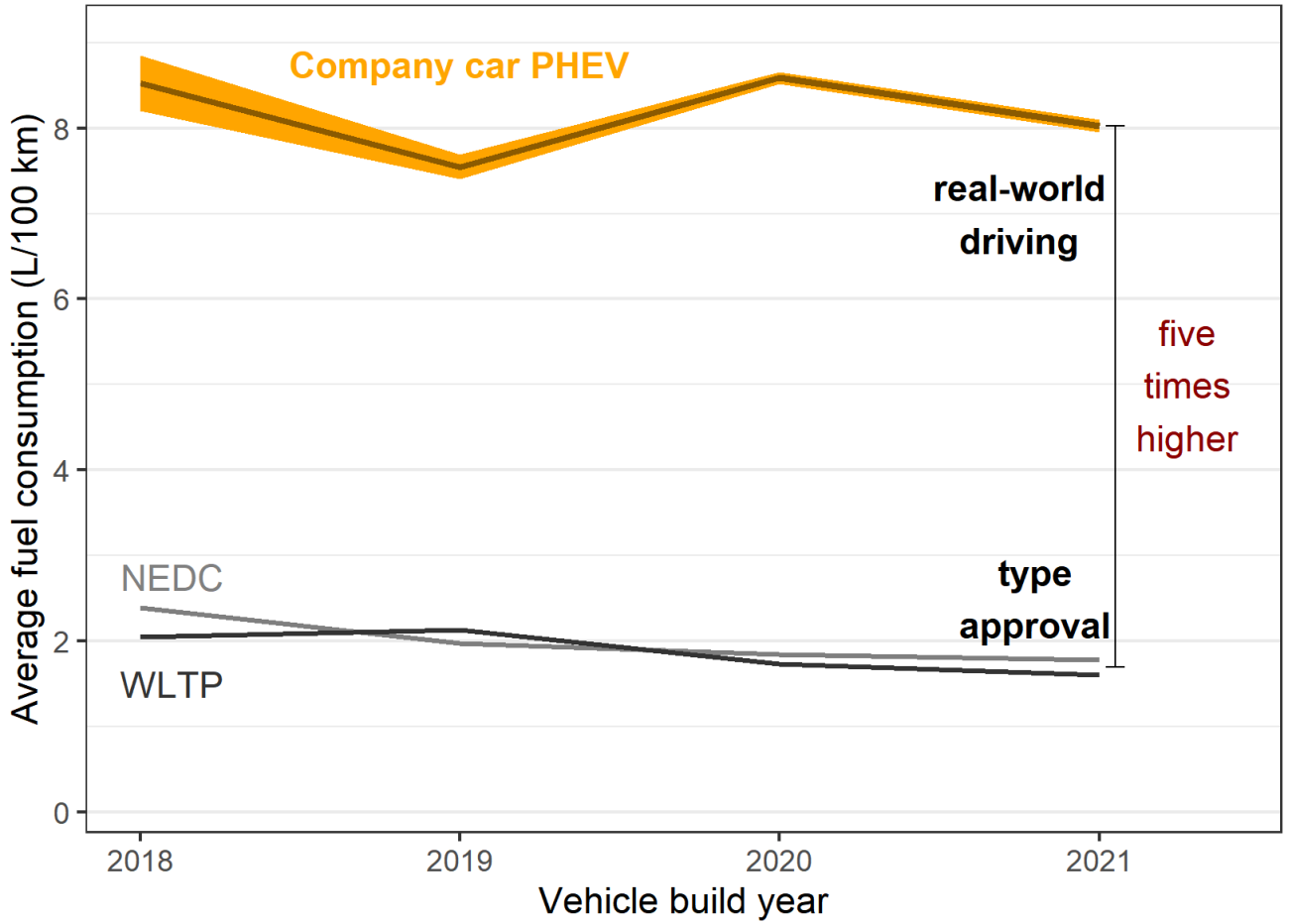


Fraunhofer ISI

Real-world fuel consumption of private PHEV is growing but fuel consumption is even higher for company cars.

- Shown is the mean (± one standard error) fuel consumption of PHEV by construction year
- The sample mean NEDC fuel consumption is shown as dashed line (WLTP mean dashed-dotted)
- Deviation between test-cycle and actual fuel consumption is increasing for private PHEVs and high for company cars





Fraunhofer ISI

Technical factors and user behavior impact real-world PHEV fuel consumption.

- Regression results on individual vehicle level confirm earlier results on range, power, mass and user group
- and an additional increase over time

- Shown are regression results with (log of) fuel consumption and UF (quasi-binomial) as dependent variable; early preliminary results with further tests outstanding

Regression results

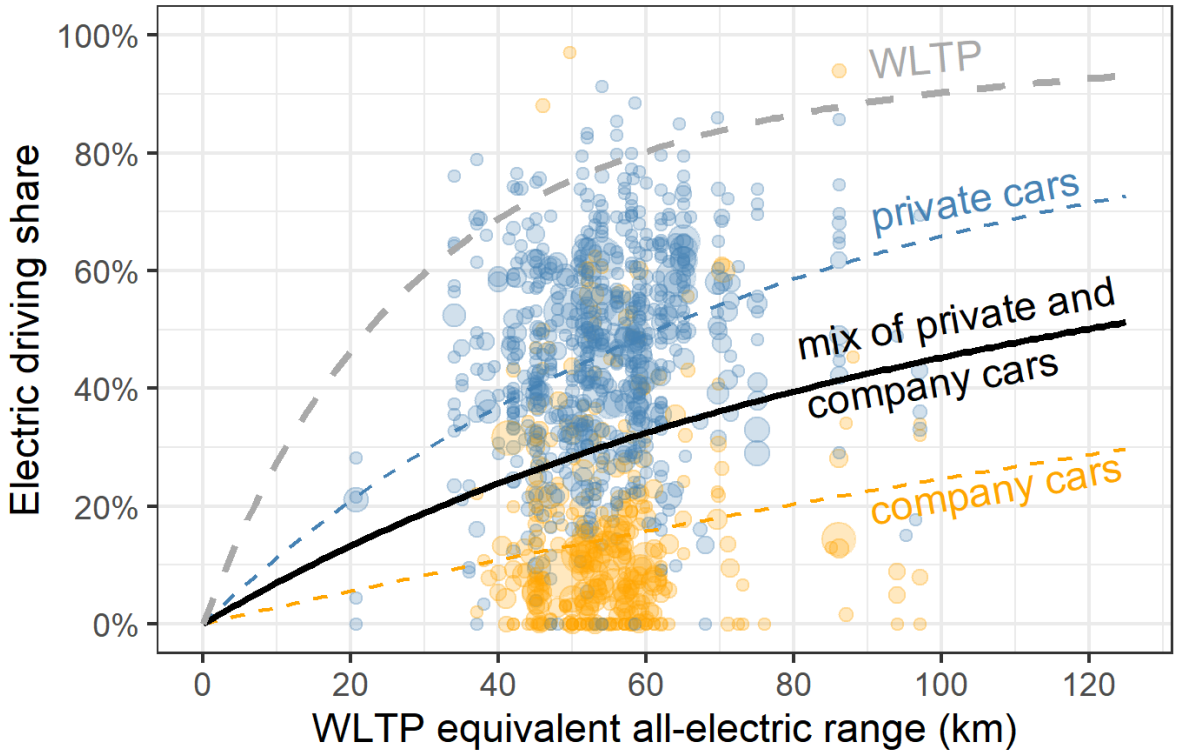
Change in factor	Change in real fuel consumption	Change in elec. drive share UF_{real}
+ 10 km NEDC range	-12%	+ 3.5 pp
+ 50 kW system power*	+5 %	-3.5 pp
+ 100 kg mass	+6 %	± 0 pp
+ 1 year	**+2.5 %**	**–0.4 pp**
User group: private	–50 %	+35 pp

* System power = engine power + electric motor power, engine power > motor power in almost all models

Fraunhofer ISI

Realistic WLTP UF are possible with modified parameters.

- The UF in WLTP has a special mathematical form that can be modified to be more realistic
- We treat the constant $d_n = 800$ km as free parameter and fit the function to the real-world data



- Real-world electric drive shares are higher for private vehicles than for company cars
- Assumptions needed for private & company car mixture to derive single parameter value
- Best estimate for mixture with ½ private + ½ company cars is $d_n = 4260 \pm 1100$ km

Plötz & Jöhrens (2021): Realistic Test Cycle Utility Factors for Plug-in Hybrid Electric Vehicles in Europe. https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cce/2021/BMU_Kurzpapier_UF_final.pdf

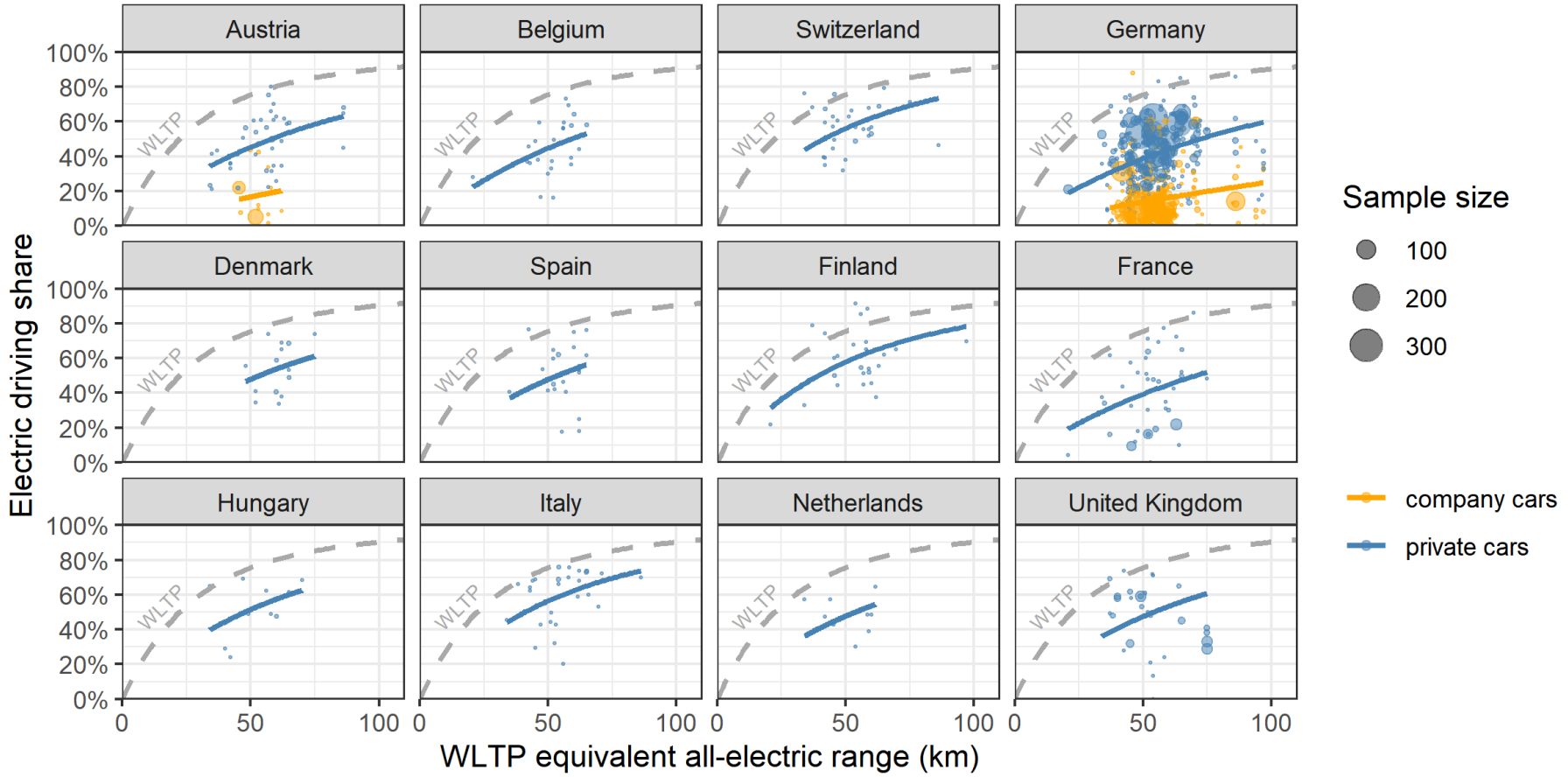
$$\mathrm{UF}(\mathrm{AER}, d_n) = 1 - \exp\left[-\sum_{i=1}^{10} c_i \left(\frac{\mathrm{AER}}{d_n}\right)^i\right],$$

where AER is the WLTP all-electric range in km and the numerical constants c_i and d_n for Europe are $d_n = 800$ km, $c_1 = 26.25, c_2 = -38.94, c_3 = -631.05, c_4 = 5964.83, c_5 = -25095, c_6 = 60380.2, c_7 = -87517, c_8 = 75513.8, c_9 = -35749, c_{10} = 7154.94$ according to (EC 2017)

Fraunhofer ISI

Actual UF is smaller than test cycle in all countries

- Shown are mean UF by PHEV model from private vehicles
- Shown are countries with N > 50
- Legend:
  - Dashed line: NEDC
  - Dot-dashed: WLTP
  - Solid line: local average
- Actual UF is smaller than NEDC in all countries



Fraunhofer ISI

Summary: New recent data confirms high deviation from official CO_2 values and indicates further increase.

Background and study

- Update of 2020 ICCT study on PHEV by Fraunhofer ISI
- Data collection completed: Primary data of 9,000 PHEV in Europe
- Results are preliminary and include only new primary data sources; Analysis is ongoing

Findings

- Results from 2020 ICCT & Fraunhofer ISI study largely confirmed
- PHEV fuel consumption and emissions at least two to four times higher than test-cycle values
- **Deviation even higher for WLTP** than for NEDC
- Deviation is **higher for company cars** than private cars
- Deviation likely to have increased for private PHEVs (likely reasons: larger engines, larger vehicles and new buyers with less environmental concern and even less charging)

Discussion and Outlook

Discussion

- All findings are preliminary but presented results appear generally robust, specific numerical values can change
- Sample small for most individual countries but general results similar in all European countries
- Results consistent with findings from 2020 study but show increase in deviation to real-world
- Deviation likely to have increased for private PHEVs,
  - potentially due to larger engines, larger vehicles and new buyers with less environmental concern / less charging)
  - simultaneous changes in mass, power, range, and user behaviour

Outlook

- More real-world data will become available from OBFCM measurements but only in a few years
- Current evidence is strong enough to correct PHEV legislation now and modify later
- Regression results indicate
  - robust time increase when controlled for other factors
  - little effect of higher electric ranges

Fraunhofer ISI

Thank you!

Dr. Patrick Plötz

Head of Business Unit Energy Economy
Competence Center Energy Technology and Energy Systems
Fraunhofer Institute for Systems and Innovation Research ISI

patrick.ploetz@isi.fraunhofer.de
@PatrickPlotz