Optimal vehicle electrification level in a battery-constrained future

Insights into optimal passenger car sales mix and GHG emissions in EU towards 2030

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Context

- **EU ambition to accelerate the electrification of road transport (Light Duty) and at the same time, becoming a global leader in sustainable battery production by developing its own production capacity [1]**
- **Large uncertainties associated with the battery production/supply capacities to meet the growing demand in EU beyond transport sector (e.g. Energy Storage Systems ESS)**
  - **Global concerns on availability of critical minerals [2, 3, 4, 5]**
  - **2030 forecasts: Concawe's literature review on battery production capacity in the EU [6, 7]**
    - *Extreme ranges between 0.3 TWh/y and 0.95 TWh/y*
  - **Situation today (2023), for the sake of comparison**
    - *__Global__ battery capacity deployed is **1.42 TWh/y**, out of which **0.163 TWh/y** are installed in **Europe** [8]*

[1] 'European Battery Alliance' (European Commission website). https://ec.europa.eu/growth/industry/policy/european-battery-alliance_en
[2] 'The Role of Critical Minerals in Clean Energy Transitions', IEA report, 2021. https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions
[3] Sustainable Fuels for the Energy Transition of Transport – Part IV. Transformation of Mobility to the GHG Neutral Post Fossil Age. https://www.fvv-net.de/fileadmin/user_upload/FVV_1378_Fuels_Study_IV_2021-10-01_presentation_final_web.pdf
[4] 'COP26: Why battery raw materials are a highly-charged topic', Wood Mackenzie, 2021 https://www.woodmac.com/news/opinion/cop26-why-battery-raw-materials-are-a-highly-charged-topic/
[5] Zeng, A., Chen, W., Rasmussen, K.D. et al. Battery technology and recycling alone will not save the electric mobility transition from future cobalt shortages. Nat Commun 13, 1341 (2022). https://doi.org/10.1038/s41467-022-29022-z
[6] PV Europe, 2020. Battery manufacturing is coming to Europe. Article published on the PV Europe website on 22 November 2020.
[7] Ultima Media, 2021. INSIGHT: Electric Vehicle Battery Supply Chain Report: How Battery Demand and Production Are Reshaping the Automotive Industry.
[8] Strat Anticipation, 2023. Private communication to be published

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Objectives

- **Concawe's study aims to investigate the following key questions:**
  - **How to make the best use of a certain level of battery production/supply towards a minimized GHG emissions of EU-wide newly registered cars towards 2030?**
    - ***Shifting from a back-to-back comparison to a systemic approach***
    - ***Putting the question of « feasibility » at the core of the issue***
    - ***Starting the mitigation of transport-related GHG "now" without waiting for the full rollout of the gigafactories***
  - **Is there a role for PHEVs?**
    - ***How much does the Utility Factor impact the results?***

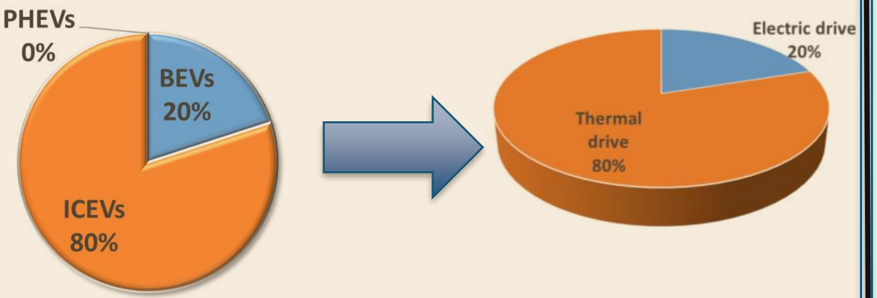
What is better?

- **Objective: Minimize WtW CO_2 emissions of 10 new passenger cars**
  - *Under a constraint of 100 kWh of batteries to produce them*

2 pathways

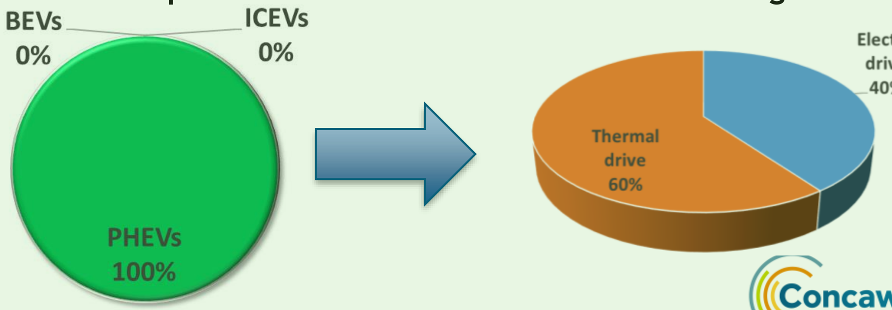
- **Batteries allocated to BEVs (50 kWh each)**
  - *2 BEVs*
  - *8 ICEVs*
  - *0 PHEVs*

Sales composition **Electrified mileage: 20%**



- **Batteries allocated to PHEVs (10 kWh each)**
  - *0 BEVs*
  - *0 ICEVs*
  - *10 PHEVs, assuming 40% electric drive (Utility Factor)*

Sales composition **Electrified mileage: 40%**



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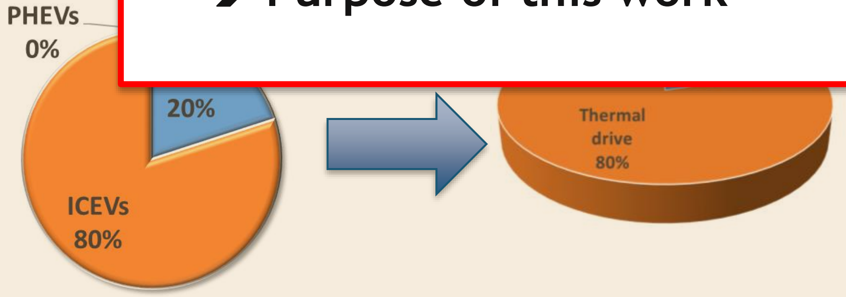
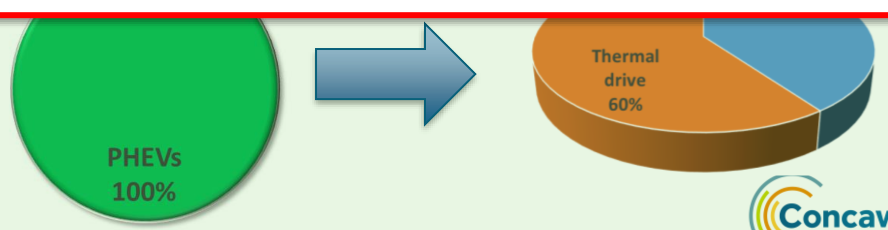
What is better?

- Objective: Minimize WtW CO2 emissions of 10 new passenger cars
  - *Under a constraint of 100 kWh of batteries to produce them*

Depending on the systemic constraints, allocating batteries to PHEVs can
- Maximize the share of electric drive
- Minimize the WtW CO2 emissions

Allocate batteries to BEVs, PHEVs or HEVs in such a manner that WtW CO2 emissions will be minimized for a range of battery constraints
- ➔ Purpose of this work





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Method & Modelling Approach

Step 1: Linear Programming Model:

- Determine optimal vehicle sales mix by minimizing WTW GHG emissions under battery supply constraints assuming fixed battery sizes for xEVs

Step 2: Non Linear Optimisation Framework:

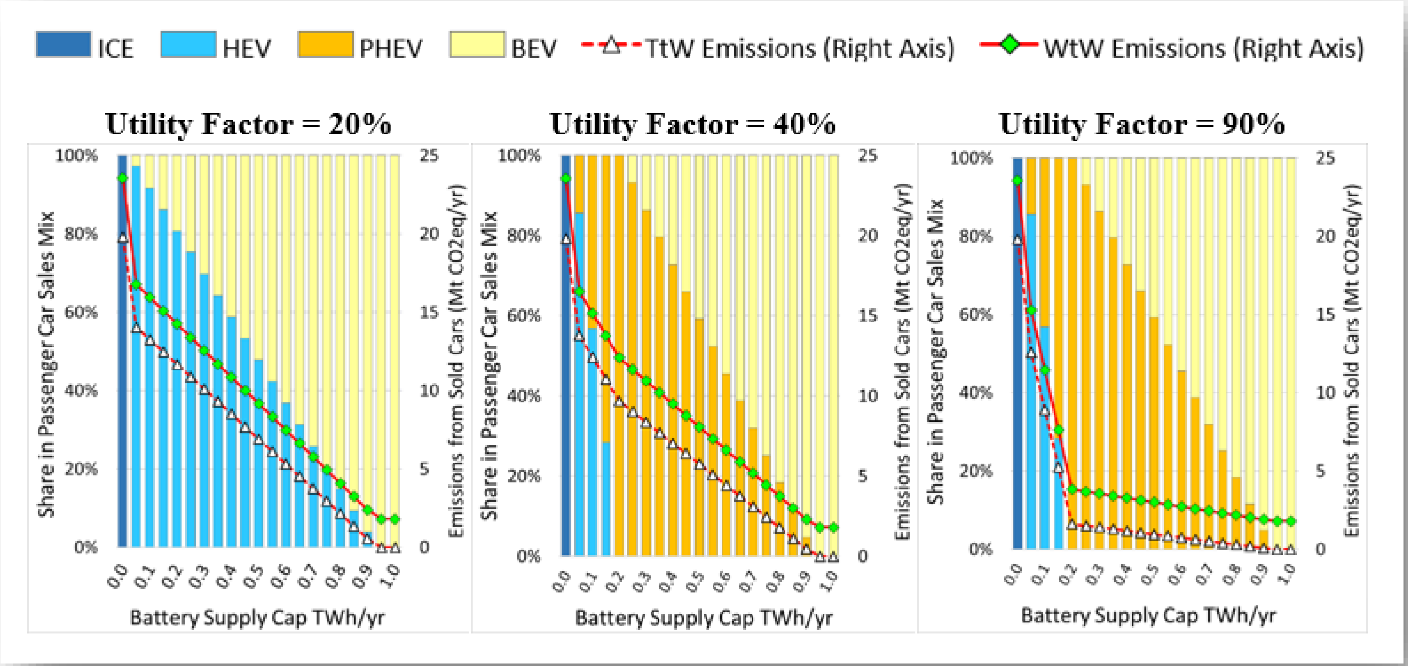
- Determine both optimal vehicle sales mix and battery size of PHEVs by minimizing WTW GHG emissions under battery supply constraint conditions

Key Assumptions:

- Battery supply cap ranging from 0.0 to 1.2 TWh/year
- Annual sale of 16 million passenger cars per year
- Annual mileage of 12.000 km per vehicle per year
- FCEVs are not taken into account in the passenger car fleet mix

"Full EV penetration" scenario, assuming the max share of 100% for the new sales of PHEV+BEV towards 2030

Linear Optimisation Results assuming fixed Battery Sizes



Fixed battery sizes:

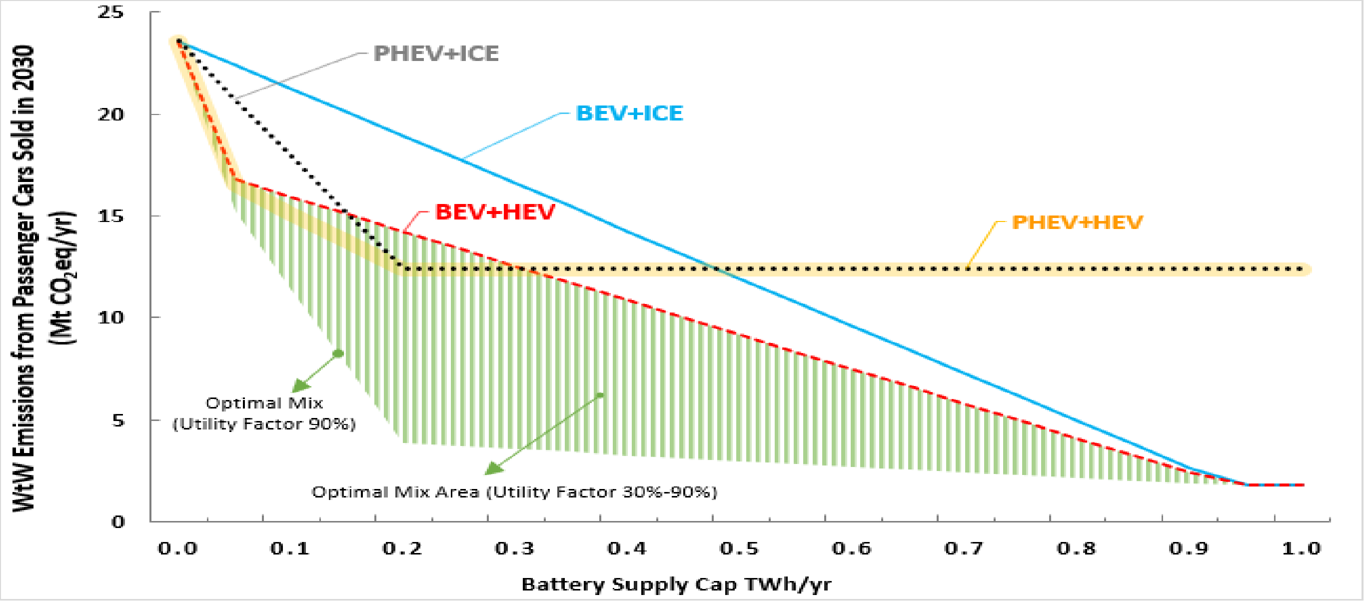
1.54 kWh (HEV)

12.5 kWh (PHEV-60)

58.4 kWh (BEV-400)

- For utility factors below 30% the optimal sales mix includes only BEV + HEV
- Break-even utility factor 30% (minimum utility factor to maintain PHEVs in the optimal mix)
- Utility factors above 30 % have essentially no impact on optimal fleet mix but a strong impact on WtW GHG emissions

Optimisation Results assuming Fixed Battery Sizes and different Sales Combinations



Fixed battery sizes:

1.54 kWh (HEV)

12.5 kWh (PHEV-60)

58.4 kWh (BEV-400)

- *Combination BEV+ICE essentially worst combination*
- *Green shaded area shows sensitivity of minimised emissions with respect to utility factor changing from 30% to 90% - Increasing PHEV is the most efficient way forward to decrease WtW emissions*
- *For a battery cap below 0.2 TWh/yr PHEV + HEV* **is** *the most effective option of all considered pairs of powertrain combinations*

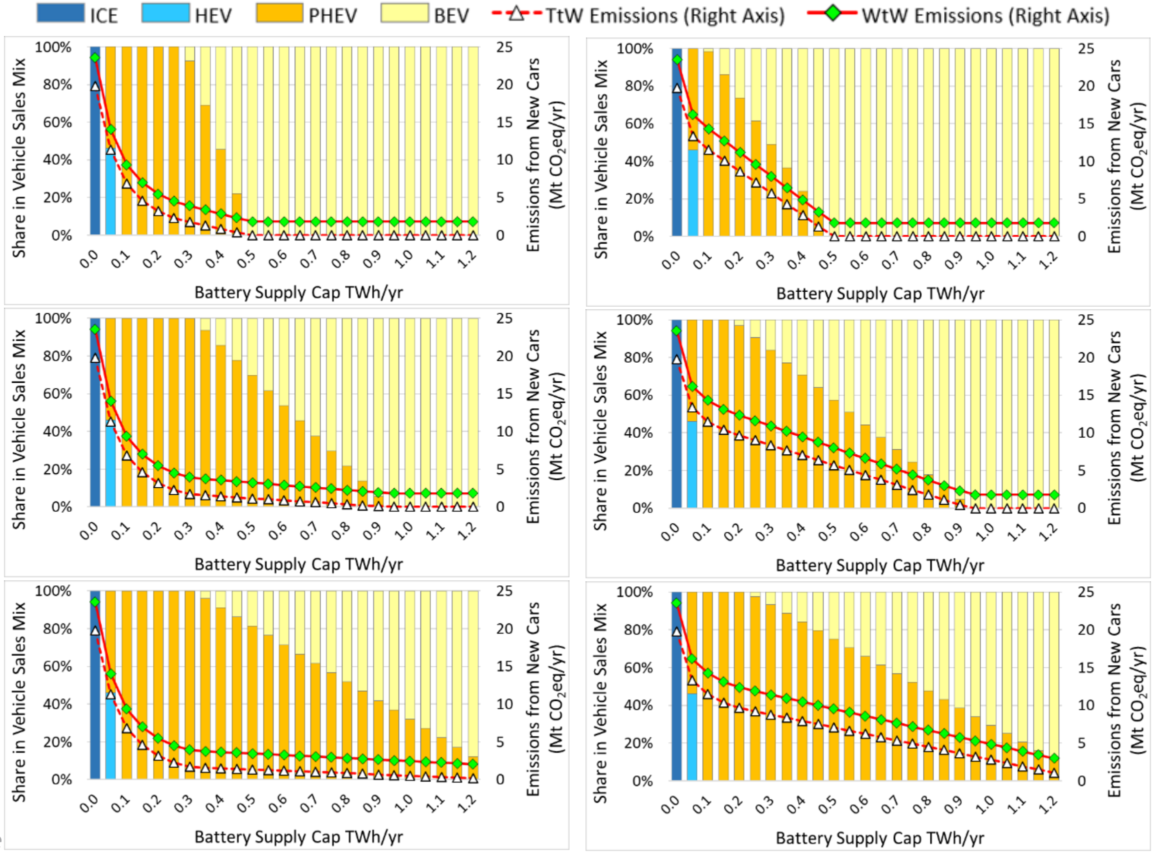
Optimisation of Sales Mix for various BEV battery sizes and Utility Factors

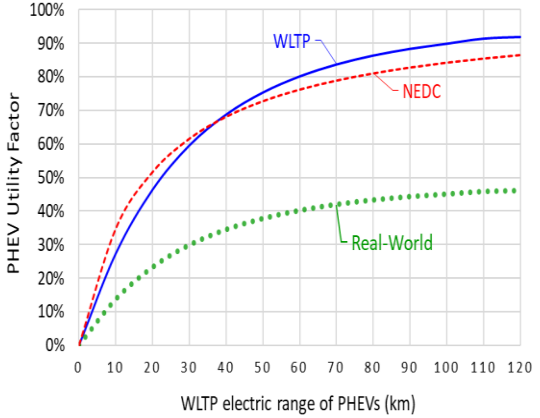
WLTP Utility Factor | **Real-World Utility Factor**

BEV-200

BEV-400

BEV-600





- **Larger BEV sizes lead to increase of PHEV share in optimal mix for both utility factors**
- **Moving from real world utility factor to WLTP utility factor has minor impact on optimal mix but reduces WtW emissions considerably**

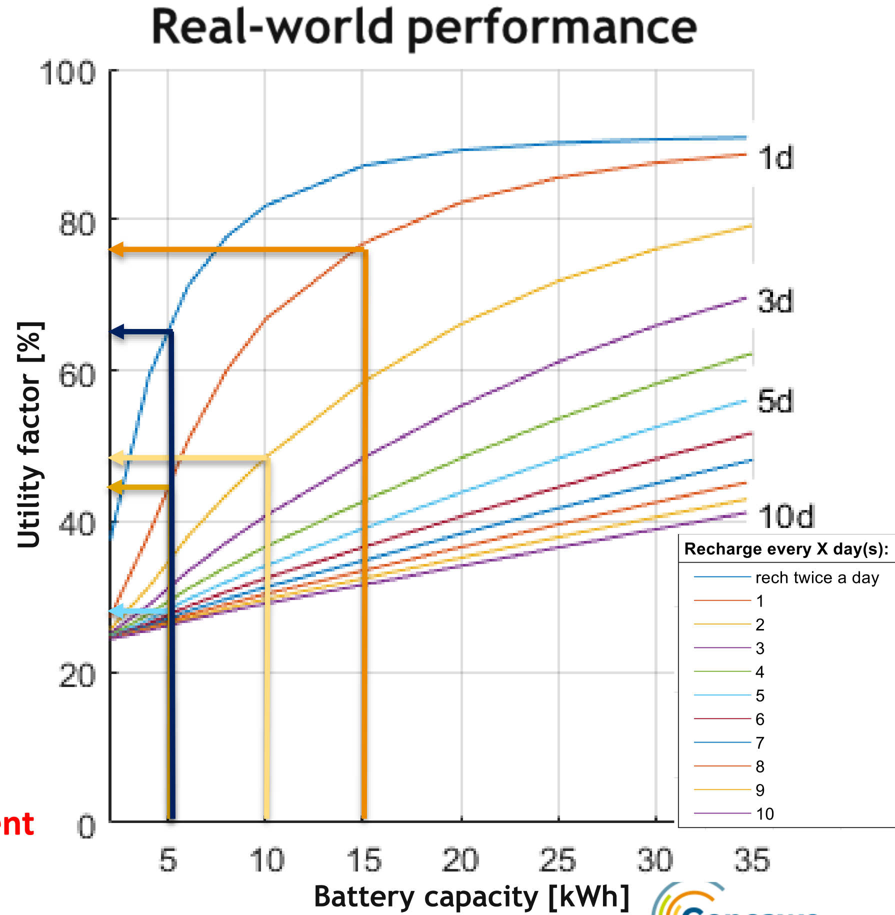
Utility Factor under Real-World Conditions using Simulations

A gasoline PHEV with a 15 kWh battery capacity recharged every day has an average utility factor of 77%

A gasoline PHEV with a 10 kWh battery capacity recharged every 2 days has an average utility factor of 48%

A gasoline PHEV with a 5 kWh battery capacity recharged every 5 days has an average utility factor of 28%

Increasing charging frequency of gasoline PHEV with a 5 kWh battery from 5 days to every day will increase utility factor from 28% to 44% and recharging twice a day increases it to 63%

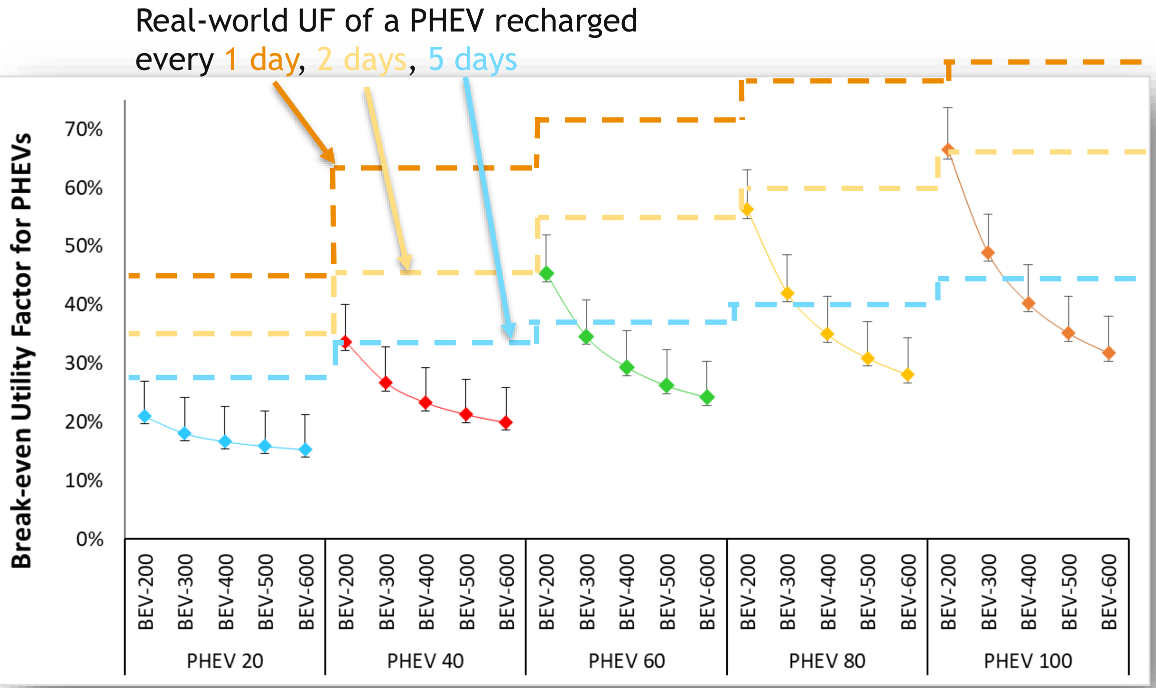


Increasing charging frequency on PHEV batteries is an efficient way to increase utility factors under real-world conditions

Break-even utility factor for various battery sizes of PHEVs and BEVs

Comparison to real-world UF for these combinations of battery capacities for PHEVs and BEVs

- Increasing the battery size of PHEVs increases the break-even utility factor
- Increasing the battery size of BEVs reduces the break-even utility factor.
- Real-world utility factor of a PHEV recharged every day is always bigger than the break-even utility factor, no matter the battery capacity
- Real-world utility factor of a small PHEV (20-40 km battery range) recharged every 5 days is still bigger than the break-even utility factor. For bigger PHEVs, it depends on the battery capacity of BEVs



Lower range PHEVs are recommended to be used in the optimal sales mix under battery constraint conditions to make best use of limited battery resources

Conclusions

Battery Supply & Demand:

- Considerable uncertainties about reliable battery supply due to growing demand worldwide
- Availability of critical minerals is not secured

Optimal electrification level:

- PHEVs would be the main component of the optimal sales mix towards 2030 even under conservative utility factors.
- To ensure the best utilisation of the limited battery resources while taking the advantage of more efficient powertrains, PHEVs recharged every 1 or 2 days would be preferable over HEVs and BEVs in reducing GHG emissions, whatever their battery capacity (20 – 100 km all electric range).
- Even if recharged only every 5 days, lower-range PHEVs (20-40 km all electric range) would still be preferable over HEVs and BEVs in reducing GHG emissions in a battery-constrained environment.
- Longer-range BEVs are not deemed as the optimal choice in terms of a systemic GHG emissions reduction. Assuming the larger battery sizes for BEVs (>400 km) under a battery-constrained condition would lead to the higher contribution of PHEVs in the optimal sales mix.

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Thank you for your attention

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