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EU-Commission JRC Contribution to EVE IWG

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European Commission

Presentation Summary (1/2)

Follow-up of the JRC activities for contribution to the EVE IWG under the "in-vehicle battery ageing" topic

Summary up to Tokyo (April 2018), i.e. what's old:

- Finalisation of the durability scenario analysis: chemistry formulation, battery architecture, vehicle technologies (BEV, PHEV);
- In-vehicle cross-validation of the model's results against experimental data from Canada;
- Scientific paper on in-vehicle battery durability submitted in Feb. 2018 to Applied Energy (to circulate as soon as it is accepted) and copy of the modeling methodology;
- Development of further scenarios for in-vehicle battery durability: 2 additional BEVs (i.e. A-segment + D-segment SUV);
- Estimation of the Years needed to reach 90% ; 80% ; 70% ; 60% ; 50% capacity fade

Presentation Summary (2/2)

Follow-up of the JRC activities for contribution to the EVE IWG under the "in-vehicle battery ageing" topic

Current Status (June 2018), i.e. what's new:

- Development of further scenarios for in-vehicle battery durability:
  - ➢duty cycle representative of geographic region, ambient temperature or customer profiles;
- List of input/output parameters of in-vehicle battery durability module of JRC TEMA platform

Performance based models (SotA)

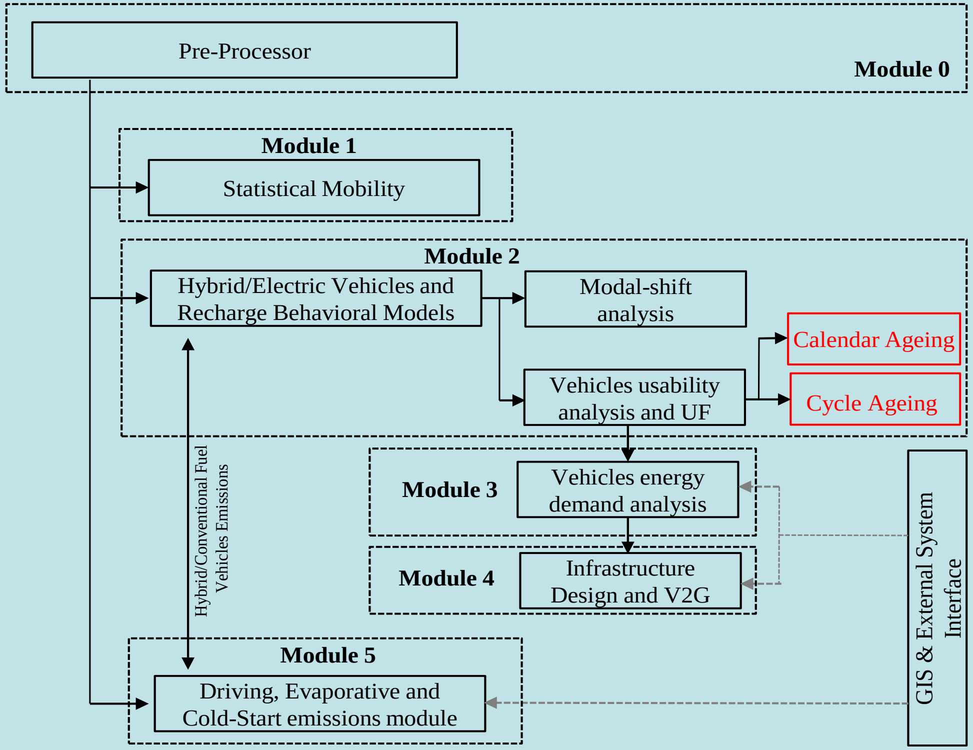
	Capacity fade		Power fade	
	Calendar	Cycle	Calendar	Cycle
$LiFePO_4$	Sarasketa-Zabala et Al. (2013/14);	Wang et Al. (2011); Sarasketa-Zabala et Al. (2013); Sarasketa-Zabala et Al. (2015);	Sarasketa-Zabala et Al. (2013);	
NCM + spinel Mn	Wang et Al. (2014);		-	-
NCM – LMO	-	Cordoba-Arenas et Al. (2014);	-	Cordoba-Arenas et Al. (2015);

Calendar + Cycle (4 Combinations):

- **#1 ($LiFePO_4$): Sarasketa-Zabala et Al. (2013/14) model for calendar plus Wang et Al. (2011) model for cycle;**
- **#2 ($LiFePO_4$): Sarasketa-Zabala et Al. (2013/14) model for calendar plus Sarasketa-Zabala et Al. (2015) model for cycle;**
- **#3 (NCM + Spinel Mn): Wang et Al. (2014) for calendar plus Wang et Al. (2014) for cycle;**
- **#4 (NCM-LMO): Wang et Al. (2014) for calendar plus Cordoba-Arenas et Al. (2015) for cycle;**

Implementation of the Performance based models into JRC TEMA (assumptions, 1/2)

TEMA Structure



Vehicle Electric Architecture (examples)

PHEV

BEV 1

BEV 2

	Vehicle Type	Battery Size [Wh]	Battery Shape	No. of Cells [#] and Type	Reference Voltage [V]	Electric Architecture
T-Shaped	PHEV	16,000	T-shaped	192 – pouch	365	2P-96S
Parallelepiped	BEV 1	24,000	Parallelepiped	192 – pouch	360	48S-2P-2S
Flat-shaped	BEV 2	85,000	Flat	6,912 - cylindrical	345	16S-72P-6S

	Usable Energy at BoL [Wh]	Usable Energy at EoL [Wh]	Reserve [% of battery capacity]	Energy consumption [Wh/km]
T-shaped (PHEV)	12,000	9,600	25%	205
Parallelepiped (BEV 1)	18,000	14,400	15%	210
Flat-shaped (BEV 2)	63,750	51,000	15%	265

Implementation of the performance based models into JRC TEMA (assumptions, 2/2)

The models have been implemented by adopting the following assumptions:

- **the calendar and cycle capacity fades are calculated at cell level (uniform ageing assumption);**
- **the model assumes average quantities in the reference period per each vehicle for DOD, C-rate, Ah-throughput and temperature;**
- **DOD and temperature are assumed equal to the battery values, consistently with the uniform fade assumption, whilst the C-rate and Ah-throughput are scaled from the battery level down to the cell;**
- **the battery temperature is regulated by the BMS between 22 °C and 27 °C during the driving and recharging phases (cycle capacity fade modelling), whilst it assumes the ambient temperature in the parking phase (calendar capacity fade modelling);**
- **The model capacity fade is calculated at the net of the capacity fade reserve. i.e.:**

$$Q_{loss\text{-}total} = Q_{loss\text{-}calendar} + Q_{loss\text{-}cycle} - \text{Reserve}$$

- **5 recharge strategies adopted:**
  - ✓ **Str. 1 = Long Stop Random AC;**
  - ✓ **Str. 2 = Short-Stop Random DC;**
  - ✓ **Str. 3 = Night AC - Str. 4 = Smart AC;**
  - ✓ **Str. 5 = Long-Stop AC 3-phases;**

- **5 vehicle segments:**
  - ✓ **B-segment BEV**
  - ✓ **D-segment premium BEV**
  - ✓ **D segment PHEV**
  - ✓ **2 additional BEVs (i.e. A-segment + D-segment SUV)**

Summary of the logical passages

#1

Performance-based models

(validated on exp. at cell-level)

#2

3 vehicle reference architectures

(from cell-to-vehicle)

#3

Real-world

Driving data

#4

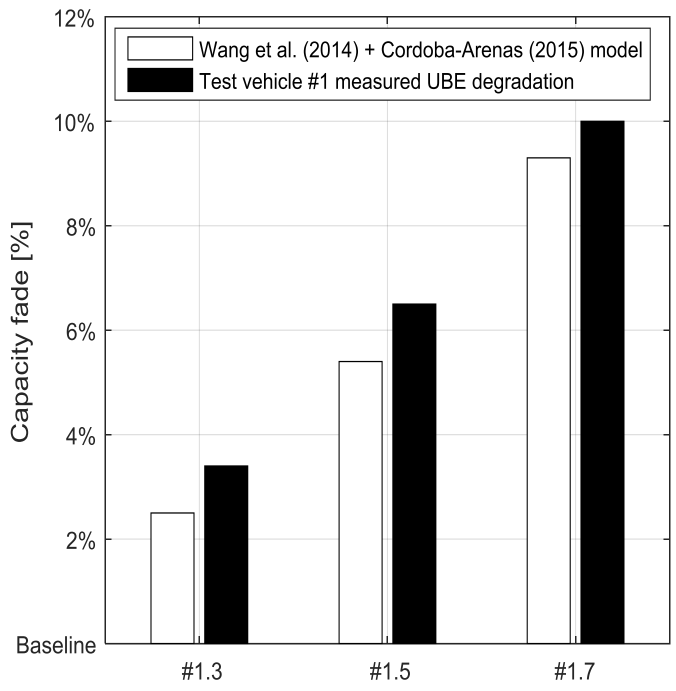
Durability Scenarios

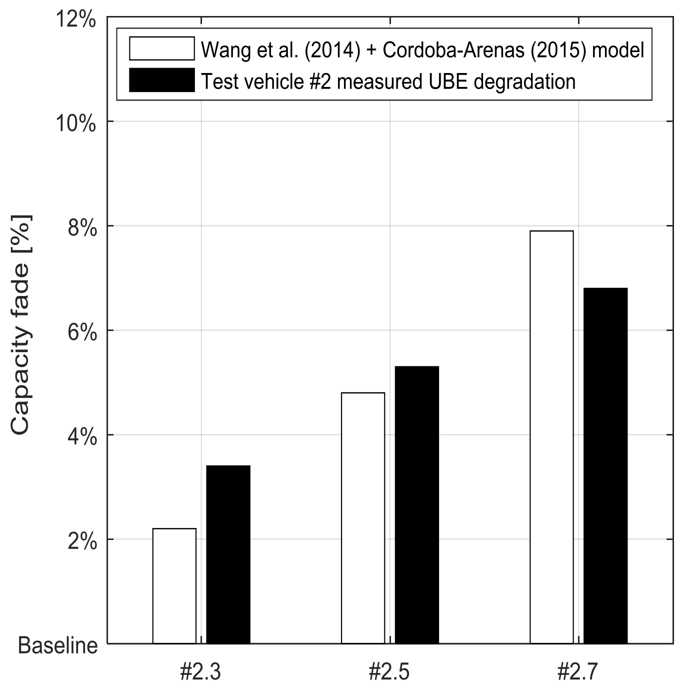
(Yrs and/or km to EoL)

Experimental data from Canada (Validation)

In-vehicle validation of the models (assumptions):

- **Uniform T, DoD, C-rate and Ah-throughput;**
- **T, DoD @ battery level;**
- **C-rate and Ah-throughput @ cell level;**
- **$Q_{loss\text{-}total} = Q_{loss\text{-}cal.} + Q_{loss\text{-}cycle}$ - Reserve(10%);**
- **NCM-LMO model (closer to real LEAF chemistry i.e. $LiMn_2O_4$ with $LiNiO_2$)**





The results will be described in the scientific paper:
"Capacity fade of Lithium-ion automotive batteries under real-world use conditions", Submitted in Feb. 2018.

Further Scenarios explored

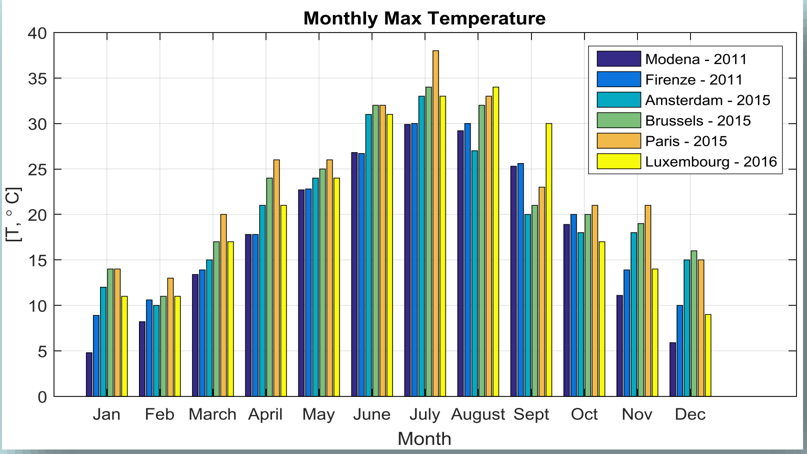
New scenarios include:

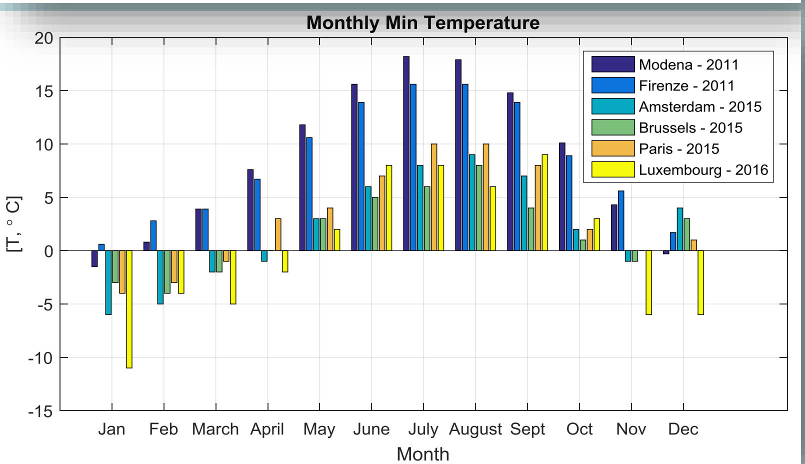
- Different duty cycle representative of more EU geographic areas; additional databases included in the analysis;
- Analysis of the BEV1, BEV2 and PHEV1 vehicles:
  - Focus on NCM-LMO chemistry;
  - 5 recharge strategies per 5 user bins (as before);
  - Estimates of the Years needed to reach 80% capacity fade, 100,000km and 160,000km.

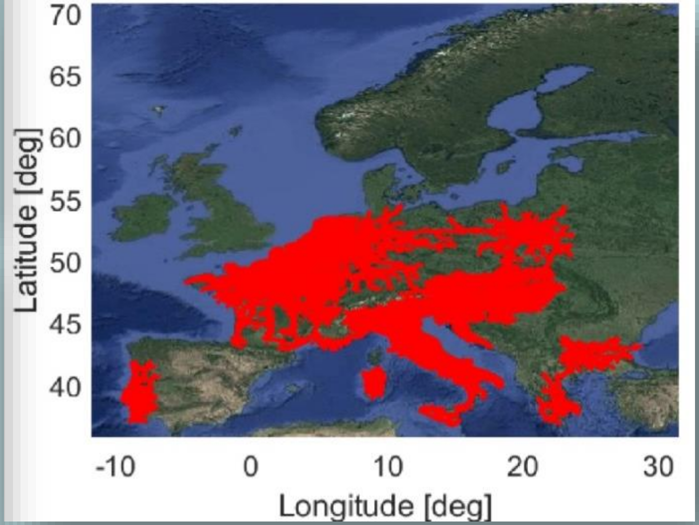
EU-wide extension of the activity data

		No. of days [#]	No. of vehicles [#]	Records [$\cdot 10^6$]	Trips [$\cdot 10^6$]	Total trips lengths [km$\cdot 10^6$]	No. of trip per day (mean) [#]	Trip length [km] (mean)	Daily driven distance (mean) [km]
Private Vehicles	Province of Modena	31	16,263	16.00	1.9	14.98	6.6	7.8	51.9
	Province of Florence	31	12,478	32.01	2.6	20.66	6.4	8.0	51.3
	Province of Amsterdam	7	197,756	466.28	1.1	19.86	1.9	19.7	37.2
	Province of Brussels	14	96,802	277.05	1.1	11.21	7.9	7.7	55.2
	Province of Paris	7	171,220	963.27	2.3	38.39	4.2	17.0	71.7
	Province of Luxembourg	7	14,090	24.33	0.08	1.0	2.5	11.9	30.1
Commercial Vehicles	Province of Lisbon	7	7,522	66.16	0.16	2.48	5.8	15.0	86.1
	Province of Krefeld	7	4,160	22.11	0.01	0.97	1.7	88.8	151.7
	Province of Warsaw	7	862	3.79	0.003	0.16	2.4	51.8	124.3
	Province of Bratislava	7	18,296	23.08	0.04	1.0	1.5	22.9	35.0
	Province of Vienna	7	9,943	49.44	0.06	2.14	13.8	37.9	134.2
	Province of Ljubljana	7	11,616	95.77	0.08	4.04	3.4	45.3	148.6
	Province of Zagreb	7	12,036	91.66	0.15	3.79	4.6	24.3	104.6
	Province of Budapest	7	32,410	320.45	0.32	14.10	4.1	44.1	179.0
	Province of Sofia	7	11,368	79.60	0.20	3.28	5.4	16.4	87.4
	Province of Athens	7	15,366	42.09	0.13	1.49	4.9	11.0	53.9
	TOTAL		**632,186**	**$2.57\cdot10^3$**	**10.19**	**139.57**			
	TOTAL (private)		**506,105**	**$1.77\cdot10^3$**	**8.56**	**101.87**			
	TOTAL (commercial)		**126,081**	**$0.80\cdot10^3$**	**1.63**	**37.70**			

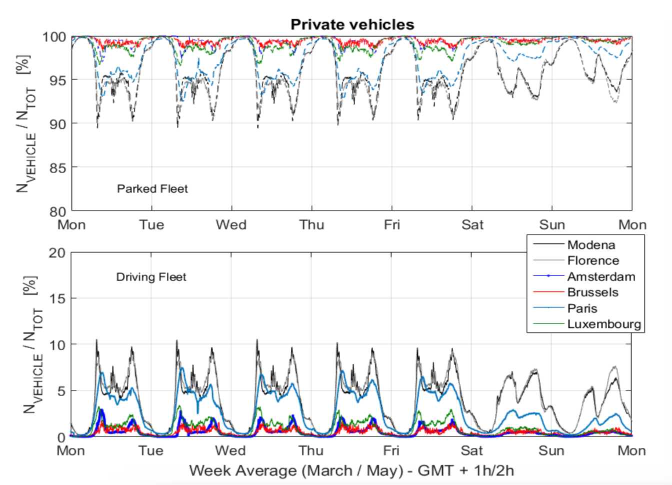
*From Octo Telematics
+ From BeMobile

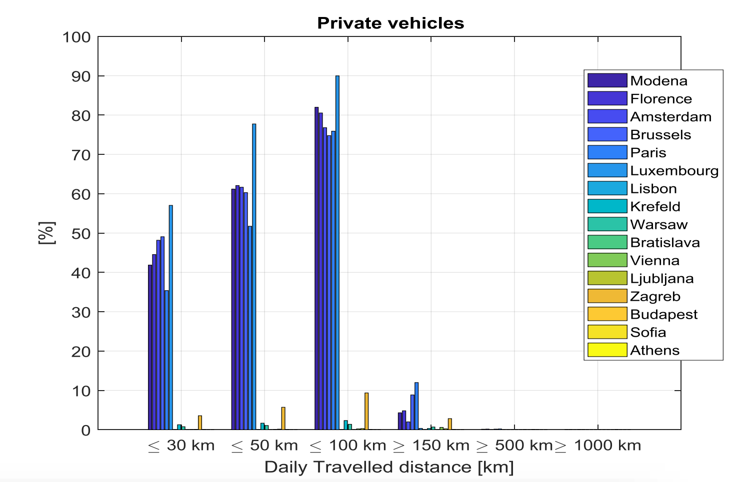


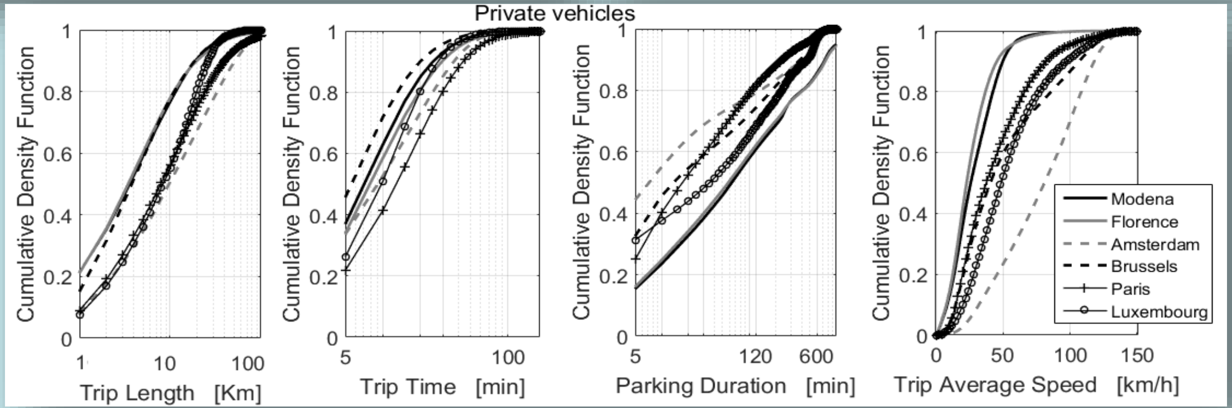




Mobility Behaviour







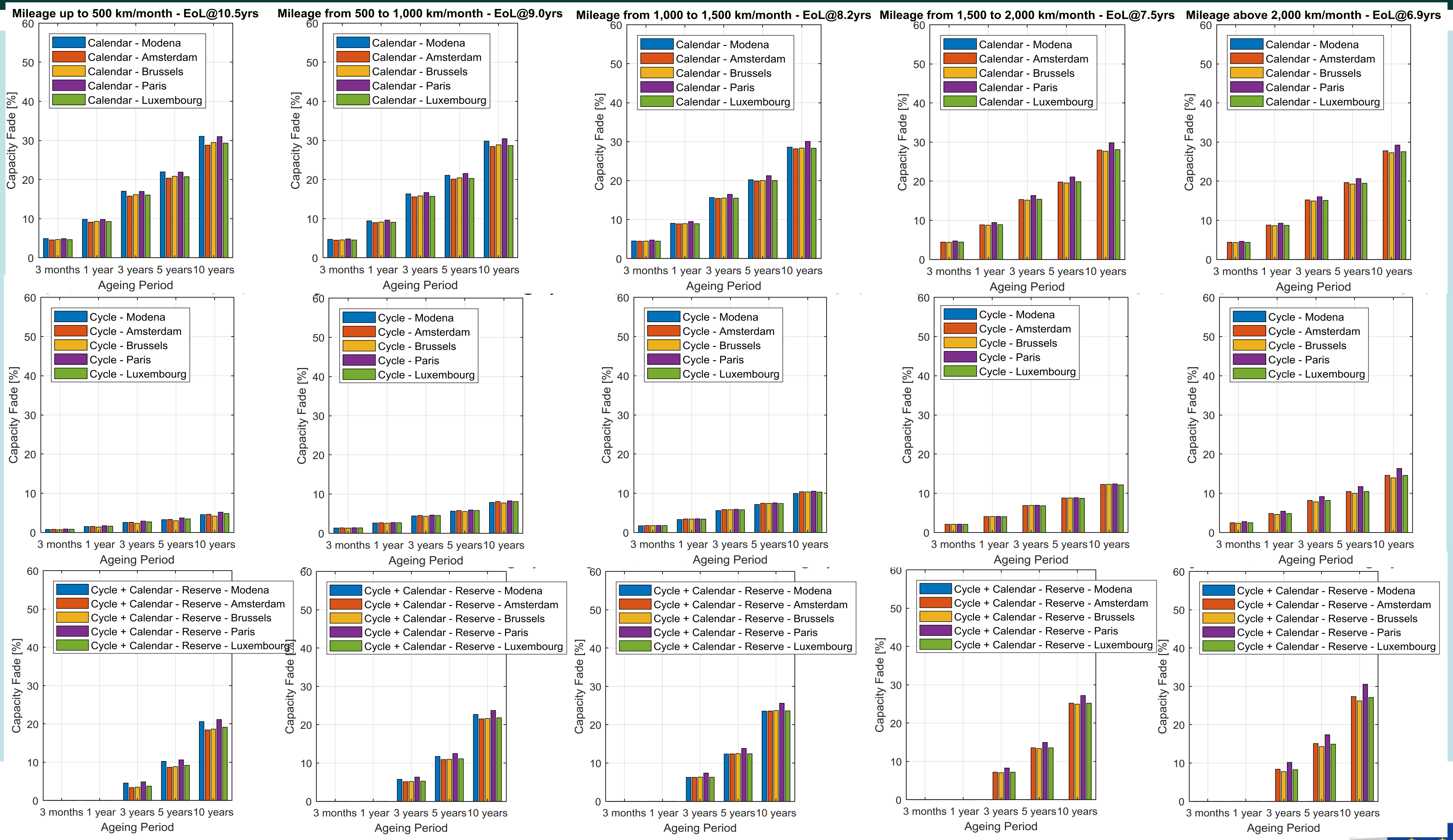
Further Scenarios (capacity fade – visualisation)

BEV 1 + Recharge Strategy 1

Calendar Ageing

Cycle Ageing

Calendar +Cycle Ageing - Reserve



Further Scenarios explored (EoL - tabulated)

EoL @ 80% capacity fade				0 - 500 km/month			500 – 1,000 km/month			1,000 -1,500 km/month			1,500 – 2,000 km/month			2,000+ km/month		
				Years to EoL	Years to 100,000 km	Years to 160,000 km	Years to EoL	Years to 100,000 km	Years to 160,000 km	Years to EoL	Years to 100,000 km	Years to 160,000 km	Years to EoL	Years to 100,000 km	Years to 160,000 km	Years to EoL	Years to 100,000 km	Years to 160,000 km
Recharge Strategy #1	PHEV-1	Modena Prov.	NCM-LMO (2015)	16.5	≥ 20	≥ 20	14.6	14.2	≥ 20	-			-			-		
		Amsterdam Prov.		18.3	≥ 20	≥ 20	15.3	11.6	18.6	13.7	6.9	11	12.5	4.9	7.8	11.3	3.4	5.4
		Brussels Prov.		18	≥ 20	≥ 20	15.2	12.6	≥ 20	13.6	6.9	11	12.8	4.8	7.7	12.1	3.7	5.9
		Luxembourg Prov.		17.5	≥ 20	≥ 20	15	11.5	18.4	13.6	7	11.1	12.6	5	7.9	11.4	3.4	5.4
		Paris Prov.		15.6	≥ 20	≥ 20	13.6	11.2	17.9	12.4	6.8	10.8	11.4	4.8	7.7	9.8	2.6	4.2
	BEV-1	Modena Prov.		9.7	≥ 20	≥ 20	8.6	12.8	≥ 20	8.2	7.9	12.6	-			-		
		Amsterdam Prov.		10.9	≥ 20	≥ 20	9.1	11.6	18.6	8.2	6.9	11	7.5	4.9	7.8	6.7	3.4	5.4
		Brussels Prov.		10.8	≥ 20	≥ 20	9.1	12.7	≥ 20	8.2	6.9	11	7.6	4.8	7.7	7.2	3.7	5.9
		Luxembourg Prov.		10.5	≥ 20	≥ 20	9	11.6	18.5	8.1	7	11.2	7.5	5	7.9	6.8	3.4	5.4
		Paris Prov.		9.4	≥ 20	≥ 20	8.2	11.1	17.9	7.4	6.8	10.8	6.8	4.8	7.7	5.9	2.6	4.2
	BEV-2	Modena Prov.		12.1	≥ 20	≥ 20	12.7	11.2	17.9	13.6	6.9	11	14.7	5	8.1	16.1	3.9	6.3
		Amsterdam Prov.		13.9	≥ 20	≥ 20	13.7	11.6	18.6	13.6	6.9	11	13.5	4.9	7.8	13.3	3.4	5.4
		Brussels Prov.		13.4	≥ 20	≥ 20	13.4	12.6	≥ 20	13.4	6.9	11	13.7	4.8	7.7	13.7	3.7	5.9
		Luxembourg Prov.		13.4	≥ 20	≥ 20	13.4	11.6	18.5	13.4	7	11.1	13.2	4.9	7.9	13.3	3.4	5.4
		Paris Prov.		12	≥ 20	≥ 20	12	11.2	17.9	12	6.8	10.8	11.9	4.8	7.7	11.8	2.6	4.2
Rech. Str. #2	BEV-1	Modena Prov.	NCM-LMO (2015)	9.3	≥ 20	≥ 20	7.9	11.7	18.7	7.1	7.1	11.4	6.6	5.1	8.1	6.2	3.7	6
		Amsterdam Prov.		10.9	≥ 20	≥ 20	8.9	11.6	18.8	7.9	6.9	11	7.2	4.9	7.8	6.5	3.4	5.4
		Brussels Prov.		10.8	≥ 20	≥ 20	8.8	12.7	≥ 20	7.8	6.9	11	7.4	4.8	7.7	6.9	3.7	5.9
		Luxembourg Prov.		10.4	≥ 20	≥ 20	8.7	11.6	18.6	7.8	7	11.1	7.1	4.9	7.9	6.5	3.4	5.4
		Paris Prov.		9.3	≥ 20	≥ 20	7.9	11.3	18	7.1	6.8	10.8	6.6	4.8	7.7	5.6	2.6	4.2
	BEV-2	Modena Prov.		11.6	≥ 20	≥ 20	11.4	11	17.7	11.3	6.8	10.8	11.2	4.8	7.7	11.2	3.4	5.4
		Amsterdam Prov.		13.7	≥ 20	≥ 20	13.2	11.7	18.7	12.9	6.9	11	12.8	4.9	7.8	12.6	3.4	5.4
		Brussels Prov.		13.2	≥ 20	≥ 20	12.8	12.7	≥ 20	12.7	6.9	11	13.1	4.8	7.7	13.2	3.7	5.9
		Luxembourg Prov.		13.1	≥ 20	≥ 20	12.8	11.6	18.6	12.6	7	11.1	12.5	4.9	7.9	12.4	3.4	5.4
		Paris Prov.		11.8	≥ 20	≥ 20	11.5	11.3	18.1	11.4	6.8	10.8	11.3	4.8	7.7	11.3	2.6	4.2

Legend	
(red)	EoL below 5.0 years;
(yellow)	EoL above or equal to 5.0 and below 10.0 years;
(green)	EoL above or equal to 10.0 years;

Hierarchical relation of the variables (tentative)

Level 1 (highest influence) →
- **Electrical architecture of the battery;**
- **Li-Ion chemistry;**

Level 2 (high influence) →
- **Driving pattern / mileage, i.e. *time, SOC, DOD, Ah, C-rate;***

Level 3 (mid-to-low influence) →
- **Temperature;**

Is the phenomenon fully comprehended? NO → More efforts needed

Input/output of in-vehicle battery durability module of JRC TEMA platform

	Input to JRC TEMA
General parameters	• Age of the car since manufacture [yrs] • Run-in km • Vehicle technology (BEV, PHEV) • EoL threshold for capacity fade and power fade
Environmental parameters	• Ambient temperature max and min for each month of the year [°C]
Duty cycle parameters	• Average number of trips per month • Average driven distance [km] • Average driving time [h] • Average driving speed [km/h] • Average energy consumption [Wh/km] • Average resting time without charging [h] • Average parking time [sec]
Charging data	• Average recharging time [h] • Recharging power [kW] • Charging mode/level • Average number of recharge per month
Battery parameters	• Battery chemistry • Battery architecture (no. of modules, no. of cells, cell voltage, cell current, series/parallel connection i.e. 48S-2P-2S etc.) • Reference battery voltage [V] • Battery capacity [Wh] • Battery reserve [%] • Average weighted battery temperature [°C] • Battery temperature min and max (BMS) [°C] • Average battery SoC min driving [%] • Average battery Delta SoC during charging [%] • Average battery SoC parking no charging [%]

HV battery chemistry	**Output from JRC TEMA**			
	Capacity fade		**Power fade**	
	Calendar	Cycle	Calendar	Cycle
$LiFePO_4$	Sarasketa-Zabala et Al. (2013/14);	Wang et Al. (2011); Sarasketa-Zabala et Al. (2013); Sarasketa-Zabala et Al. (2015);	Sarasketa-Zabala et Al. (2013);	
NCM + Spinel Mn	Wang et Al. (2014);		-	-
NCM – LMO	-	Cordoba-Arenas et Al. (2014);	-	Cordoba-Arenas et Al. (2015);

Thank you for the attention

Q&A

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