Development of a GTR on
In-vehicle battery durability

41st Meeting of the GRPE Informal Working Group
Electric Vehicles and the Environment (EVE)

EC-US/EPA-ECCC

16-17 December 2020

Joint Research Centre

Presentation Summary

- TEMA model and its use for defining minimum performance requirements
- Review of warranty data
- Position of EC, US-EPA and ECCC on the development of the GTR on In-Vehicle Battery Durability

TEMA Presentation Summary

Follow-up JRC contribution to the EVE IWG “in-vehicle battery ageing” topic

Current Status (December 2020), i.e. what’s new:

- Exploring comparison with new real-world data: PHEVs (slide 4 on)
- Capacity retention curves by TEMA (slide 10 on)
- PHEV analysis with reserve capacity of 15% vs 25% (slide 38 on)

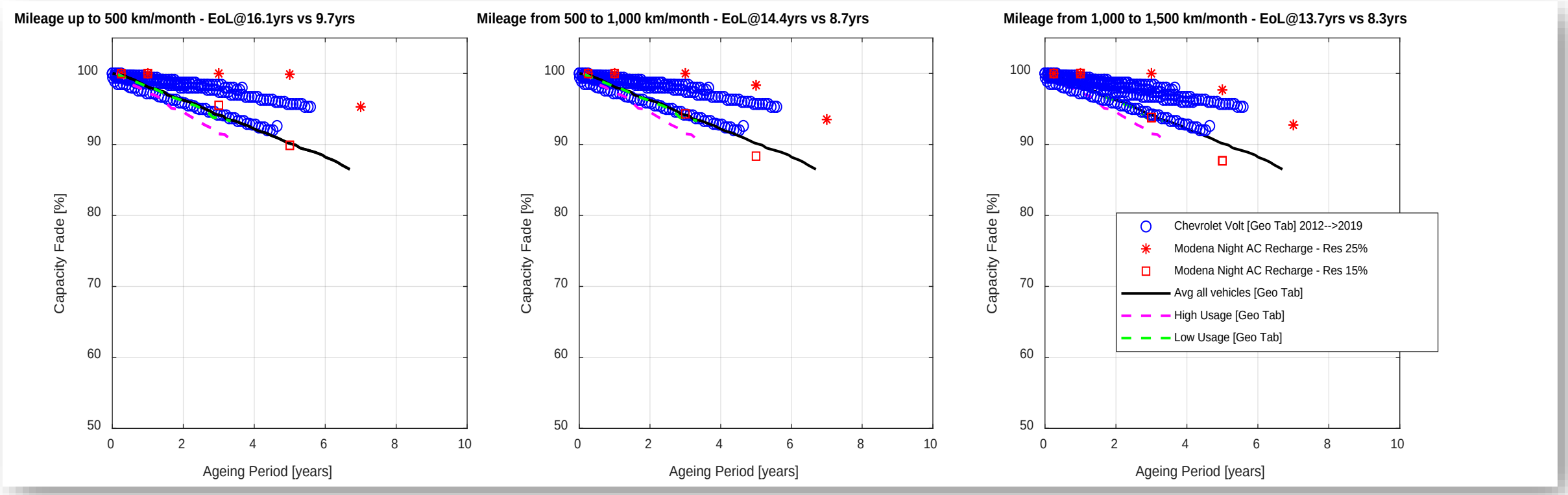
Exploring comparison with new real-world data: PHEVs

Comparing JRC TEMA ageing prediction with additional data from the field

- *What can 6,000 electric vehicles tell us about EV battery health?* Published on December 13, 2019 in Electric Vehicles by Charlotte Argue (https://www.geotab.com/)
- Compare the average battery degradation for different vehicle makes and model years, analysing the battery health of 6,300 fleet and consumer EVs, representing 1.8 million days of data.
- From the telematics data processed, providing aggregated average degradation data for 21 distinct vehicle models, representing 64 makes, models, and years.
- The degradation data displayed are the average trend line from the data analysed.
- Additionally analyses of:
  - high vehicle use
  - extreme climates
  - charging type.

https://www.geotab.com/

Comparing JRC TEMA ageing predictions with additional data from the field



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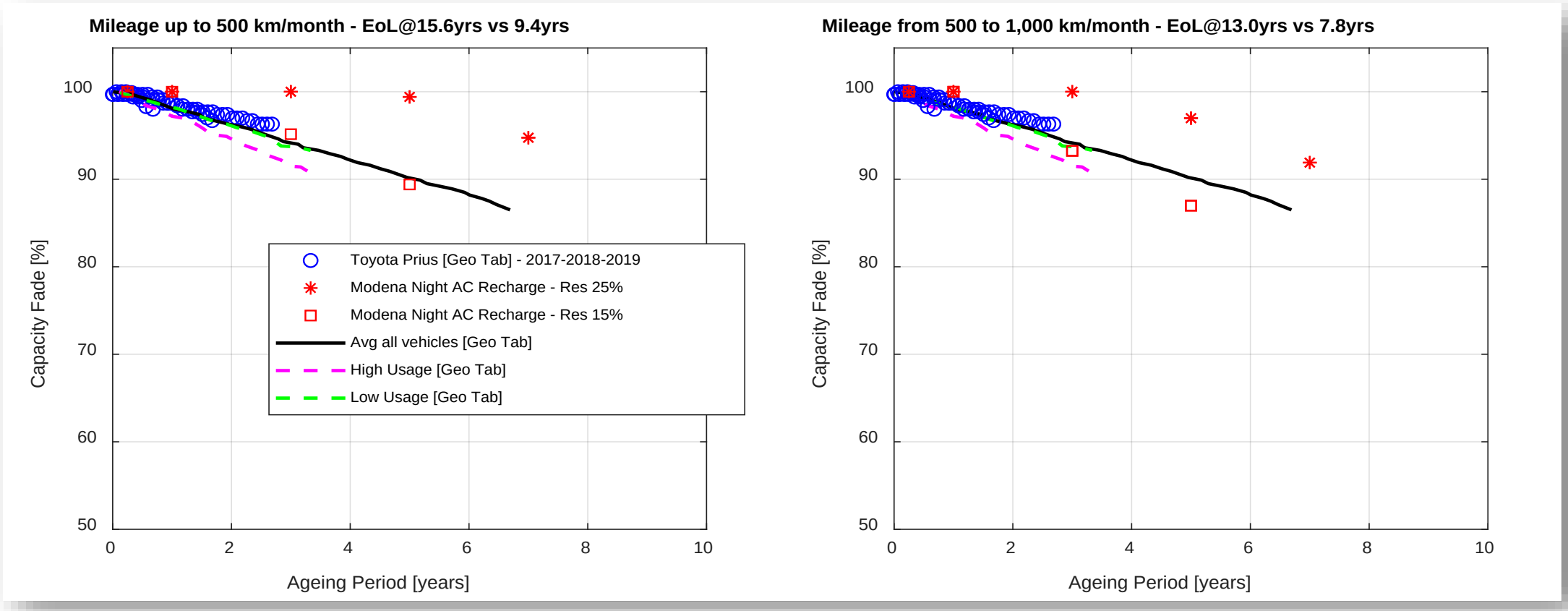
Comparing JRC TEMA ageing predictions with additional data from the field



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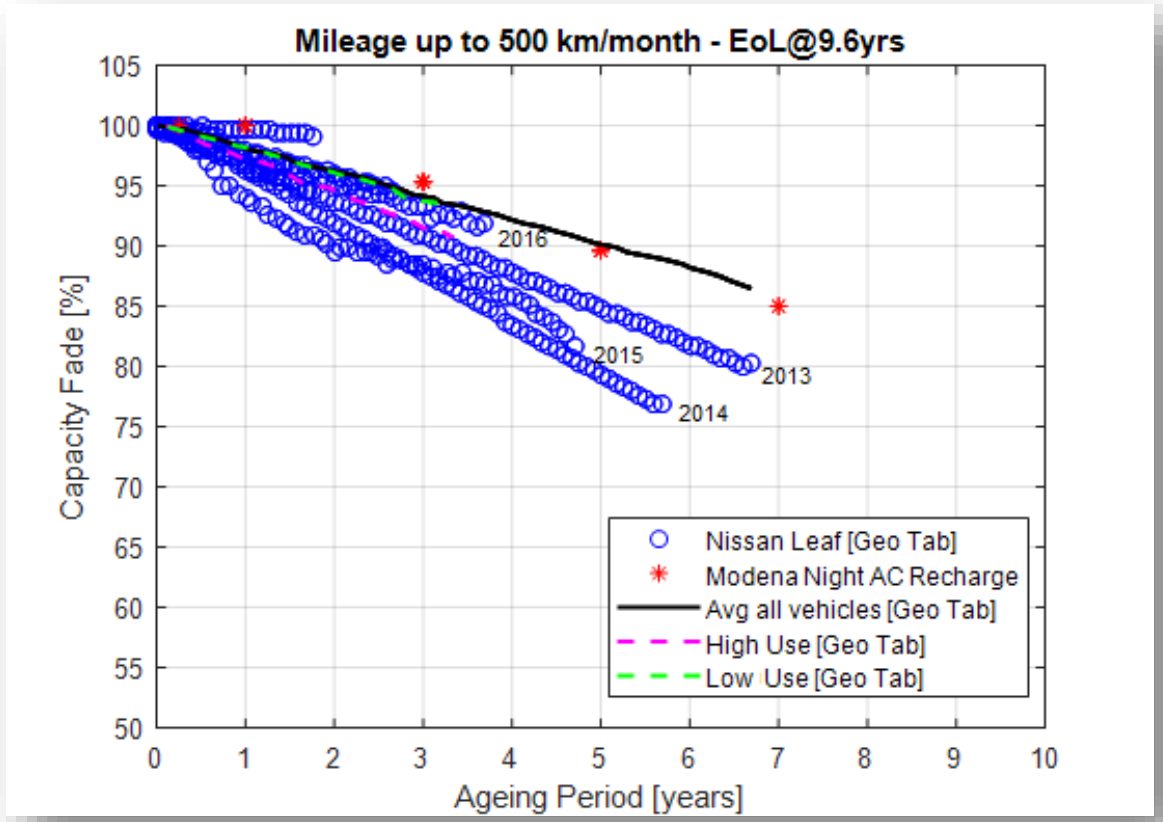
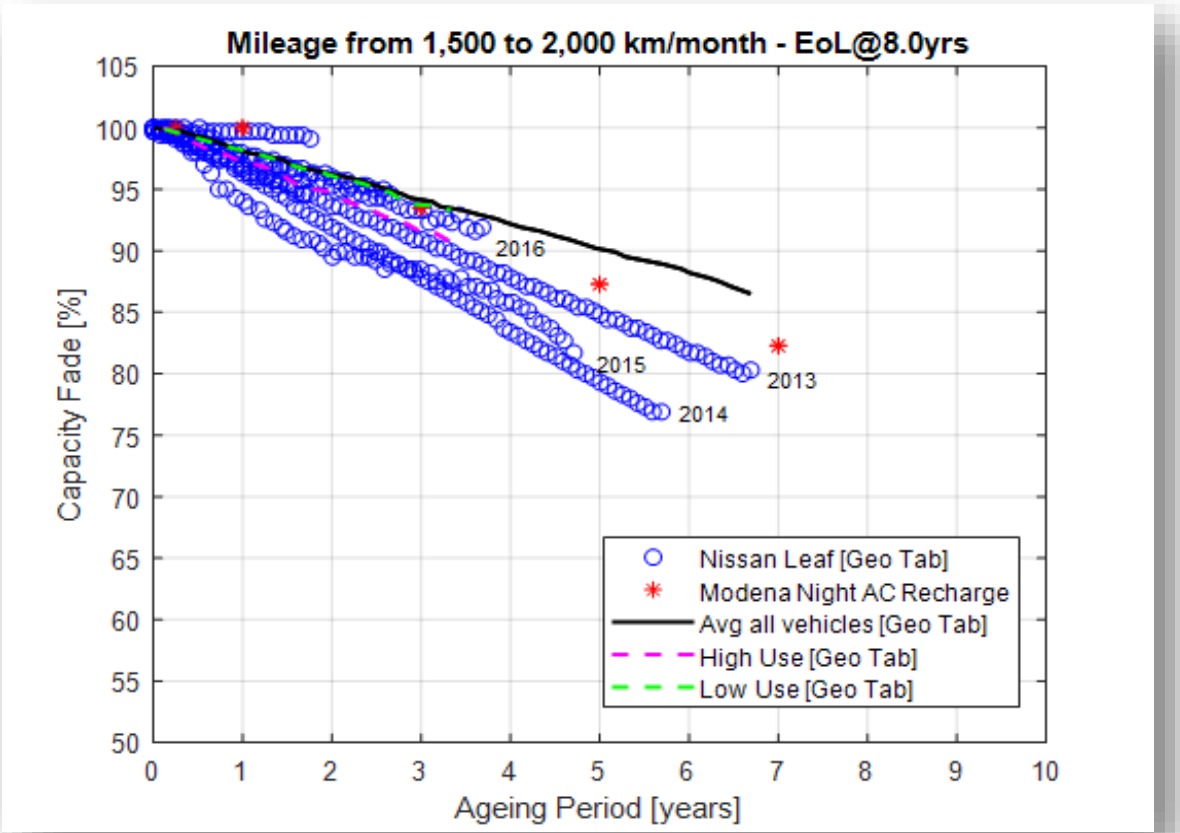
Comparing JRC TEMA ageing prediction with additional data from the field





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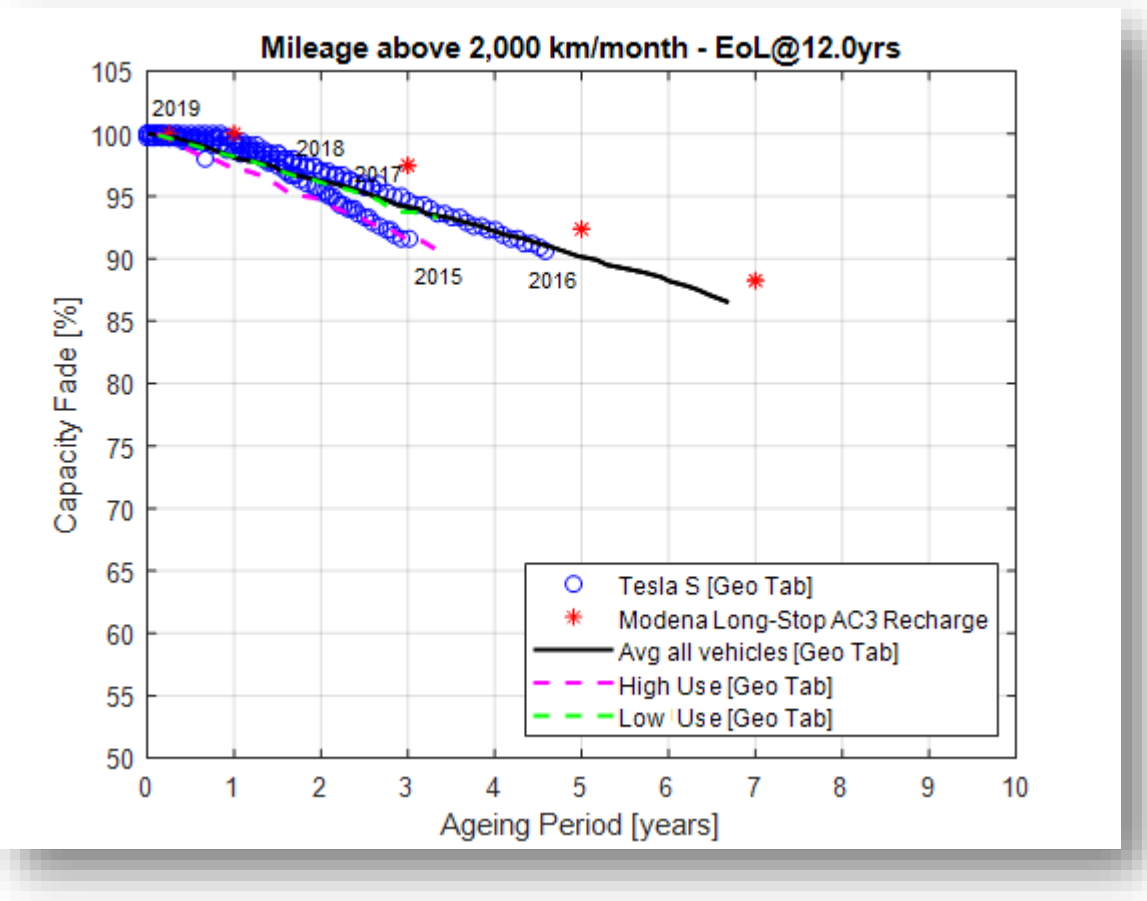
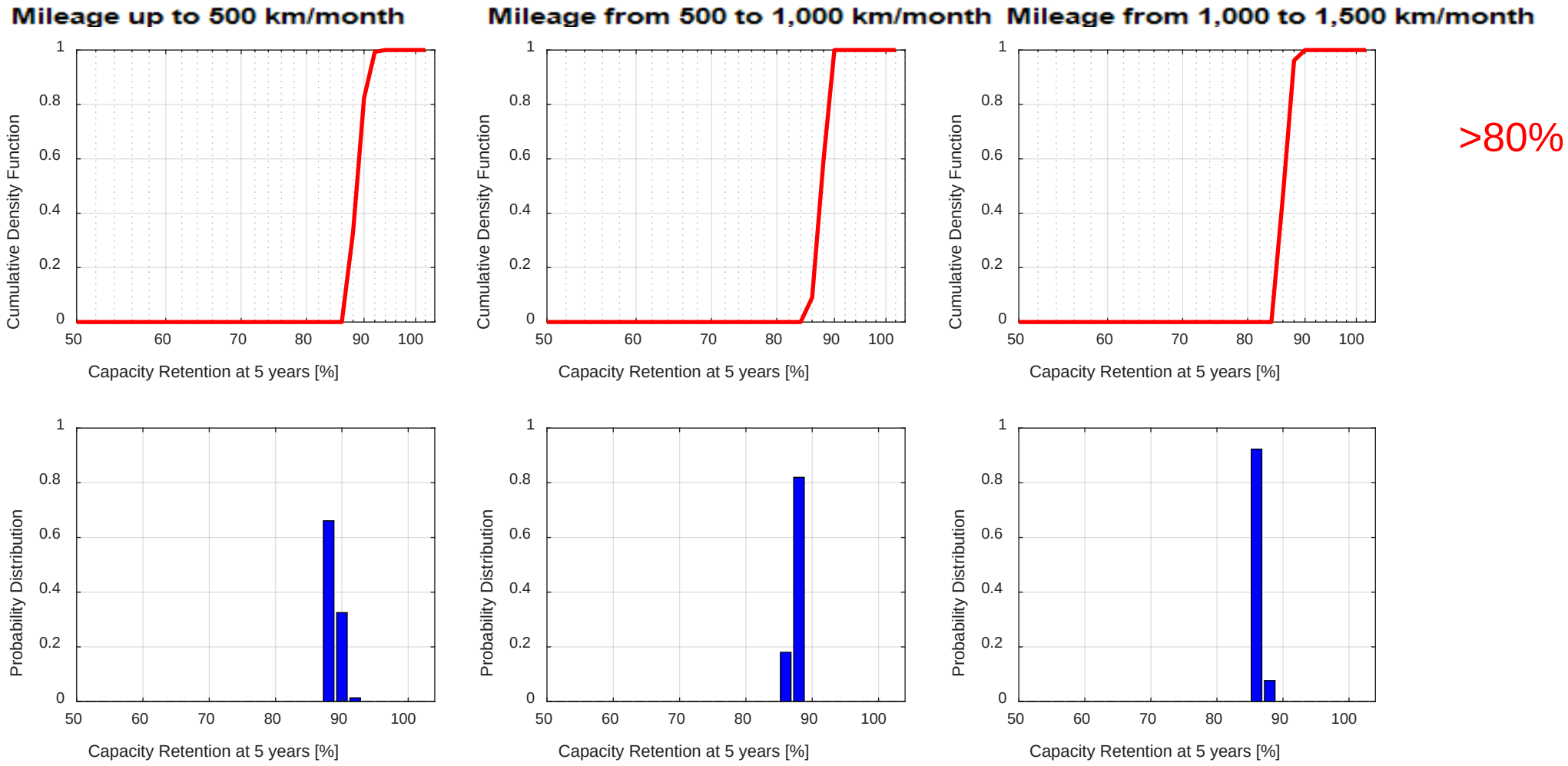
Comparing JRC TEMA ageing prediction with additional data from the field



https://www.geotab.com/

Capacity retention curves estimated by TEMA

Capacity retention at 5 years - BEV-1 – Str. 1



>80%

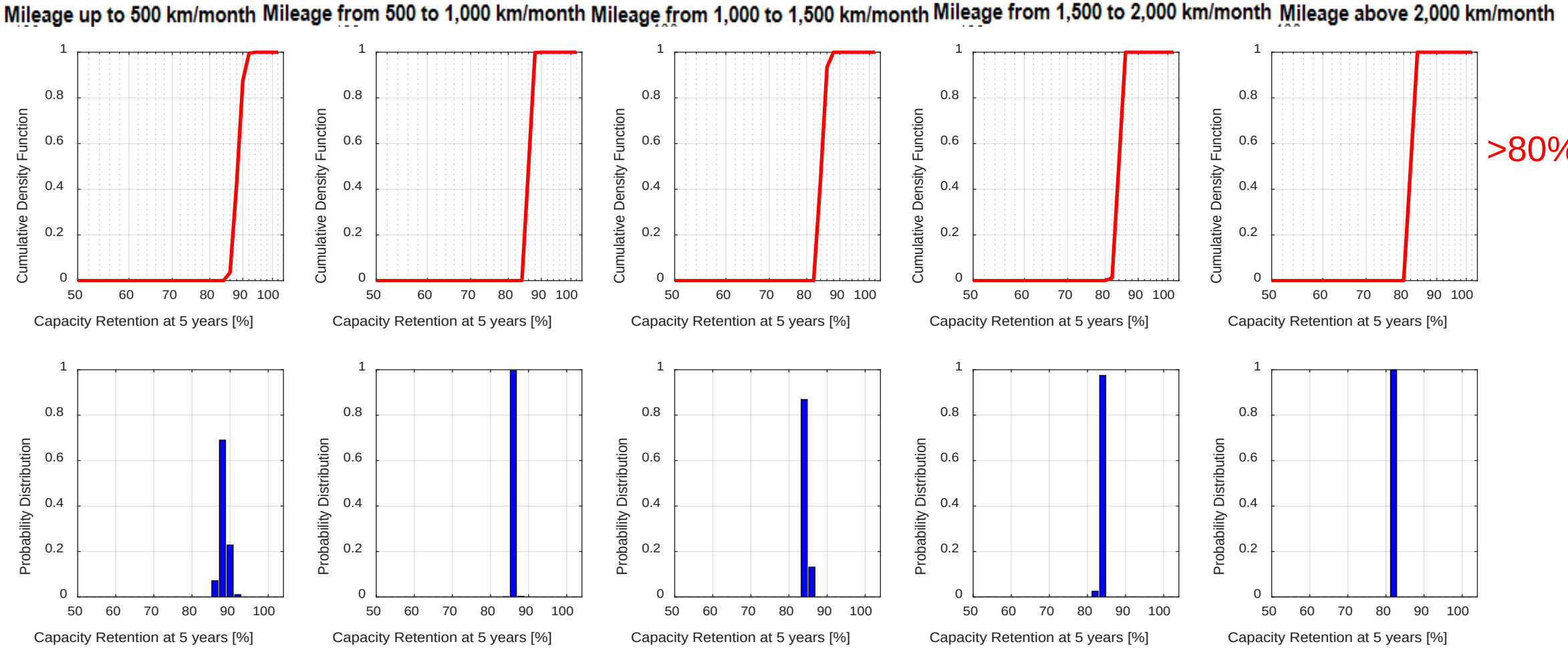
Li-Ion NCM-LMO (2015)
Modena province area

EoL 20% @ 9.7yrs

EoL 20% @ 8.6yrs

EoL 20% @ 8.0yrs

Capacity retention at 5 years - BEV-1 – Str. 2

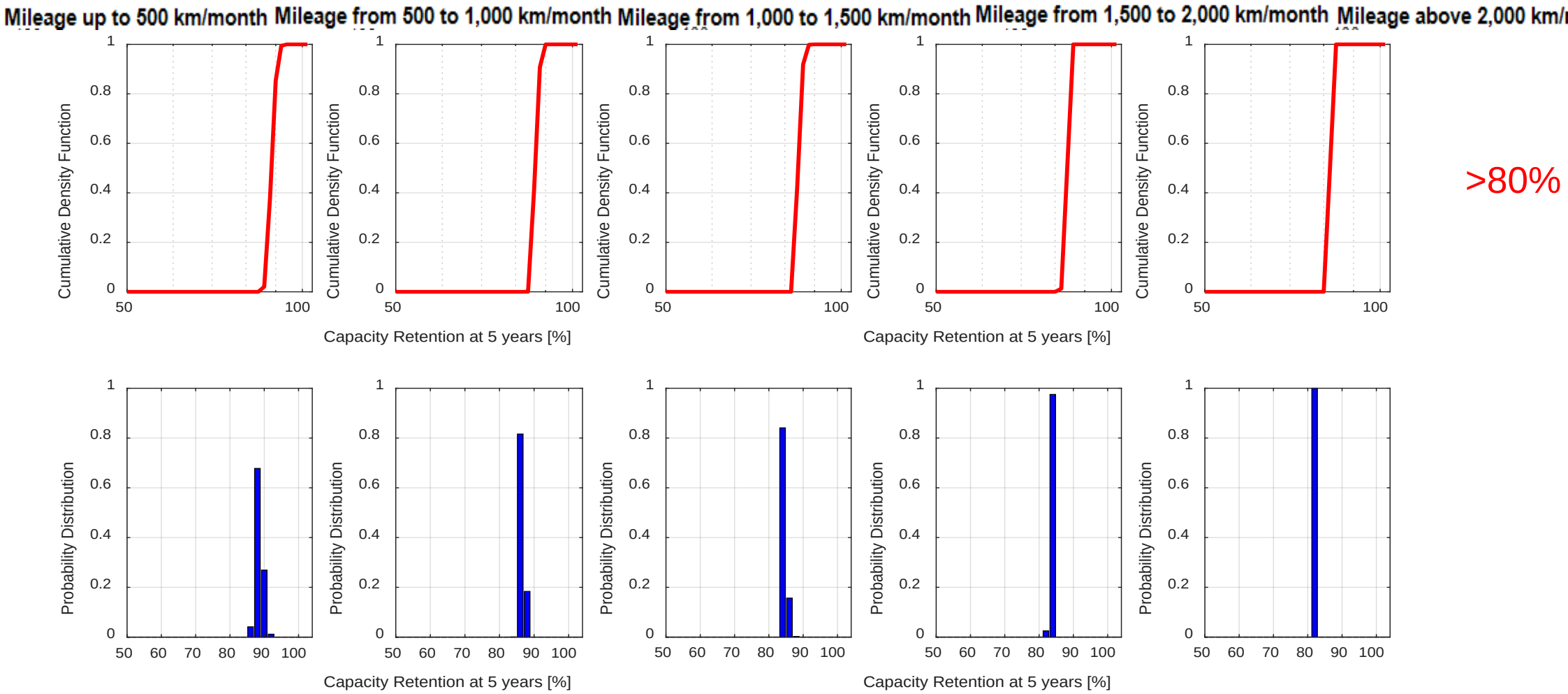


Li-Ion NCM-LMO (2015)
Modena province area

EoL 20% @ 9.3yrs | EoL 20% @ 7.9yrs | EoL 20% @ 7.1yrs | EoL 20% @ 6.6yrs | EoL 20% @ 6.2yrs

European Commission

Capacity retention at 5 years - BEV-1-Str.1 & Str. 2



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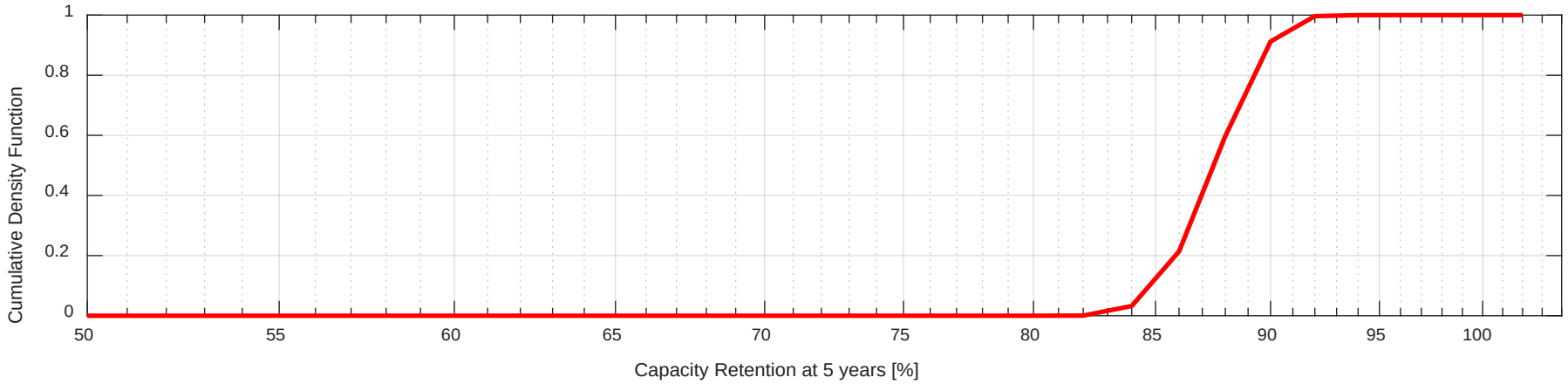
Li-Ion NCM-LMO (2015)
Modena province area

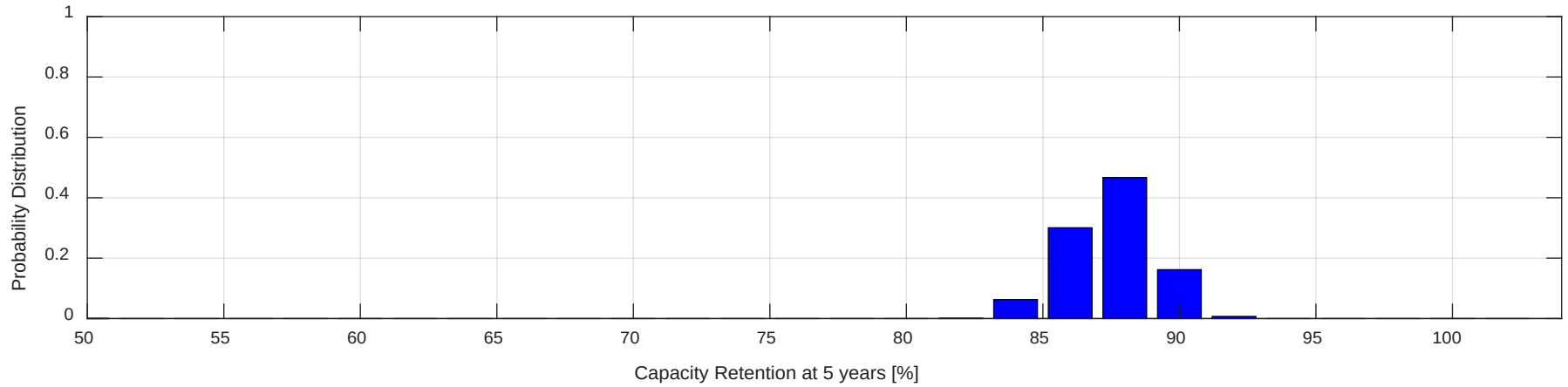
EoL 20% @ 9.3yrs | EoL 20% @ 7.9yrs | EoL 20% @ 7.1yrs | EoL 20% @ 6.6yrs | EoL 20% @ 6.2yrs

European Commission

Capacity retention at 5 years - BEV-1 Str.1&Str.2

All km/month bins distributions



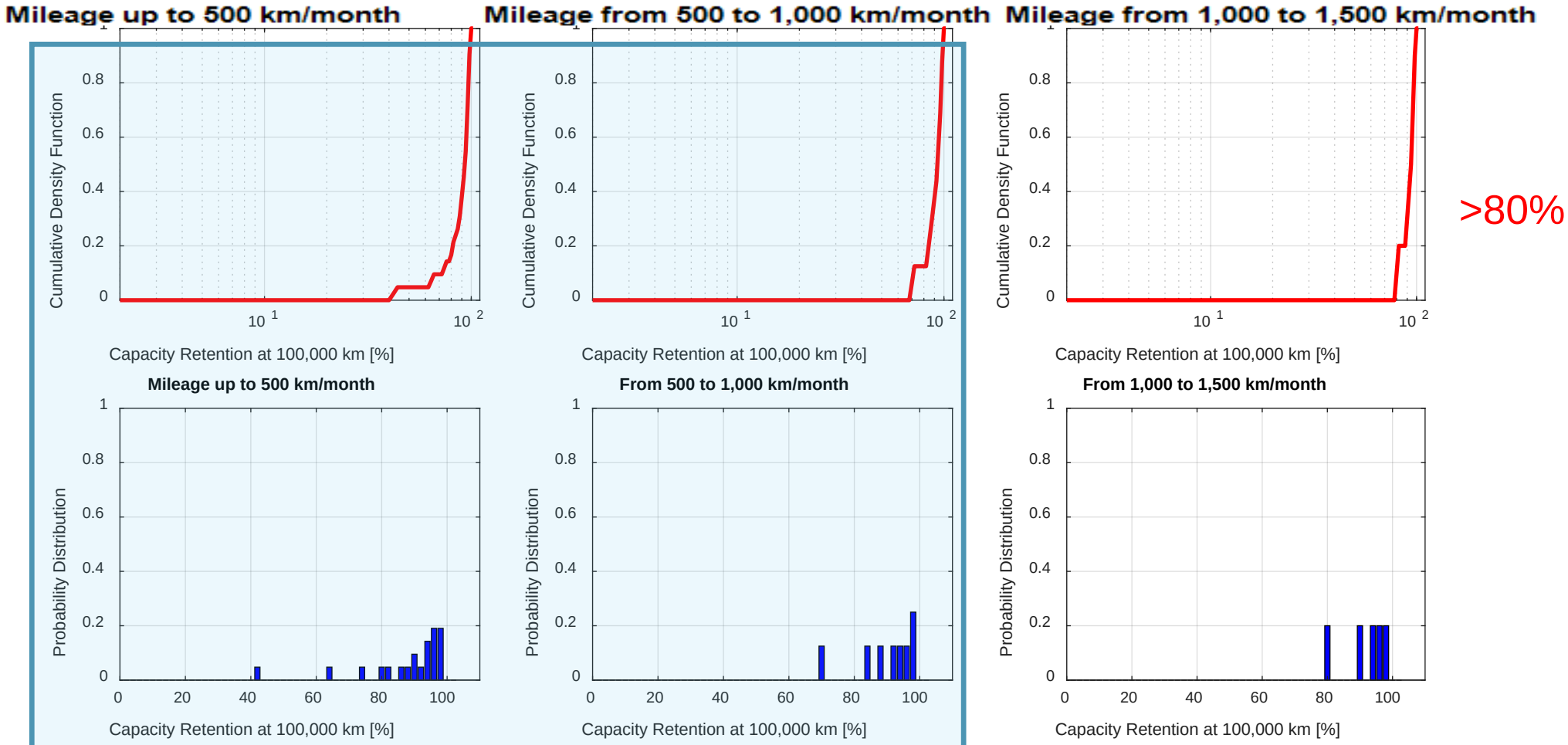


>80%

Li-Ion NCM-LMO (2015)
Modena province area

European Commission

Capacity retention at 100,000 km - BEV-1 – Str.1



>80%

Li-Ion NCM-LMO (2015)
Modena province area

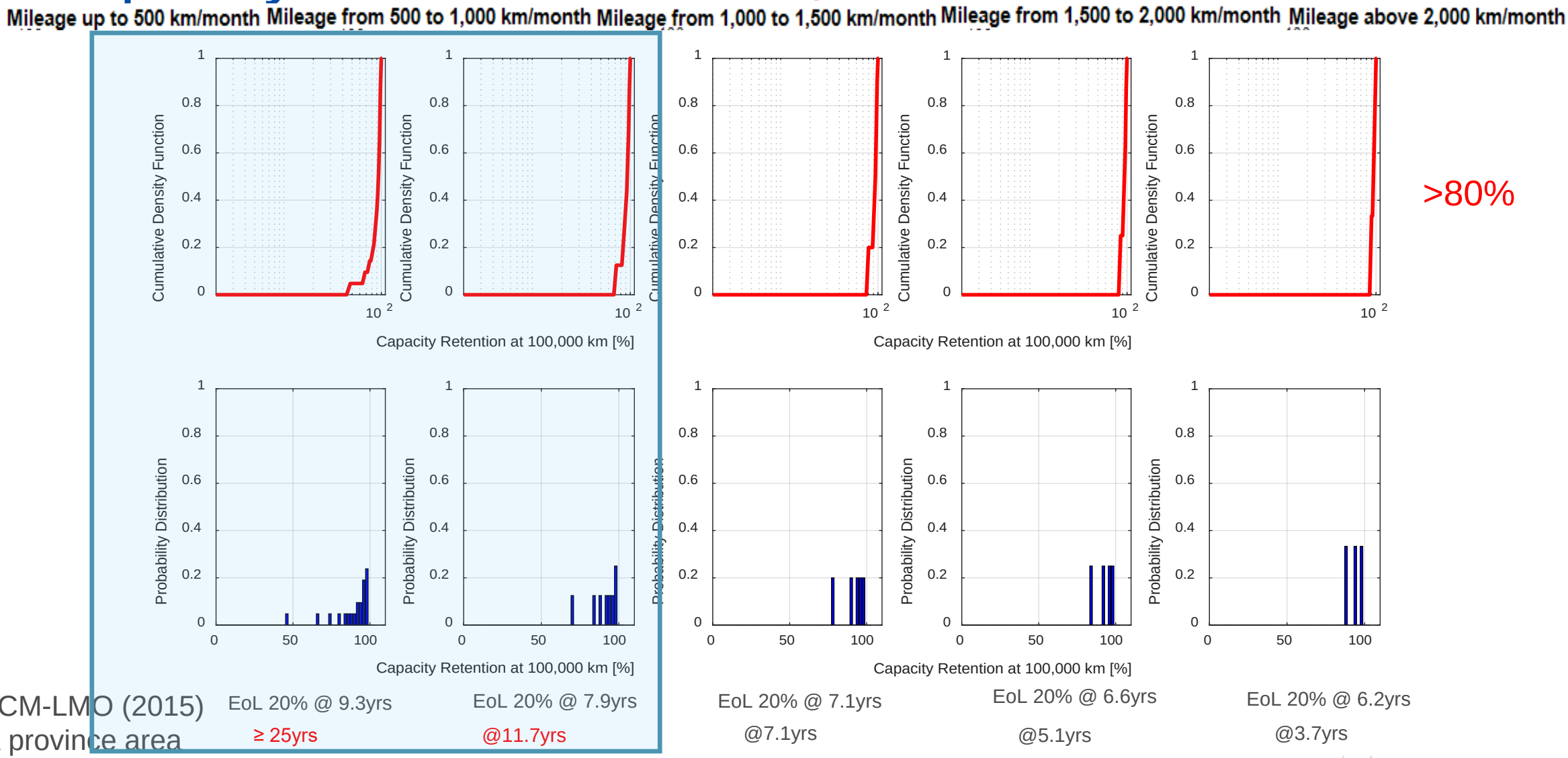
EoL 20% @ 9.7yrs
≥ 25yrs

EoL 20% @ 8.6yrs
@12.8yrs

EoL 20% @ 8.0yrs
@7.9yrs

European Commission

Capacity retention at 100,000 km - BEV-1 – Str.2



>80%

Li-Ion NCM-LMO (2015)
Modena province area

EoL 20% @ 9.3yrs
≥ 25yrs

EoL 20% @ 7.9yrs
@11.7yrs

EoL 20% @ 7.1yrs
@7.1yrs

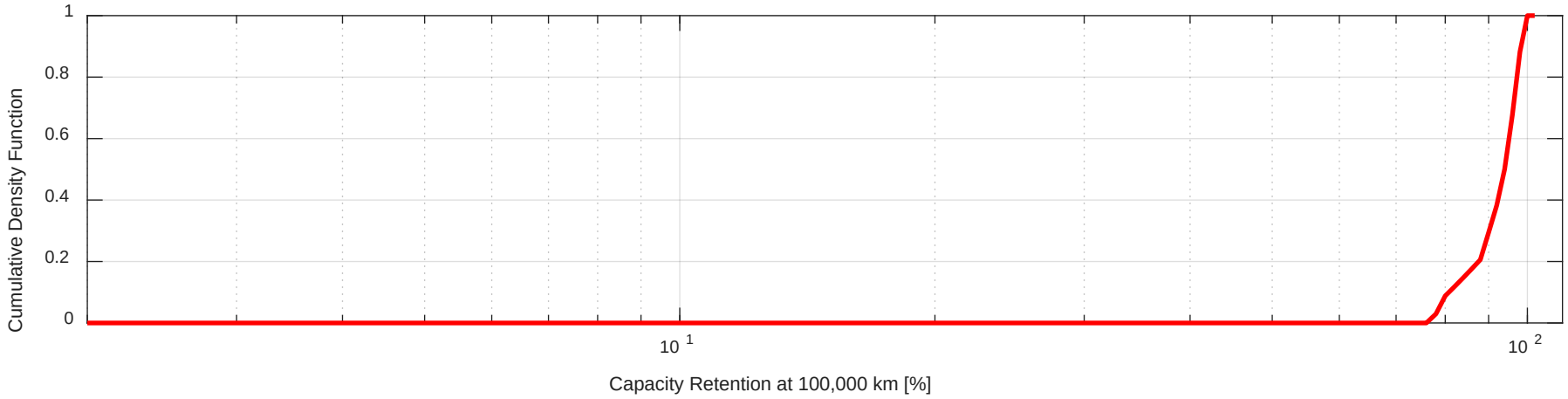
EoL 20% @ 6.6yrs
@5.1yrs

EoL 20% @ 6.2yrs
@3.7yrs

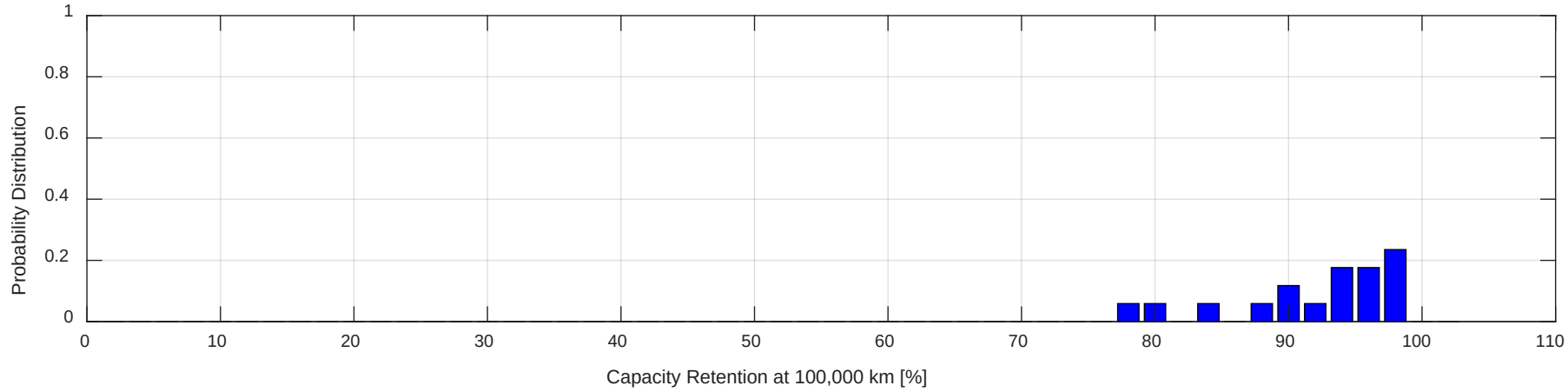
European Commission

Capacity retention at 100,000 km – BEV-1- Str.1&Str.2

All km/month bins distributions



>80%

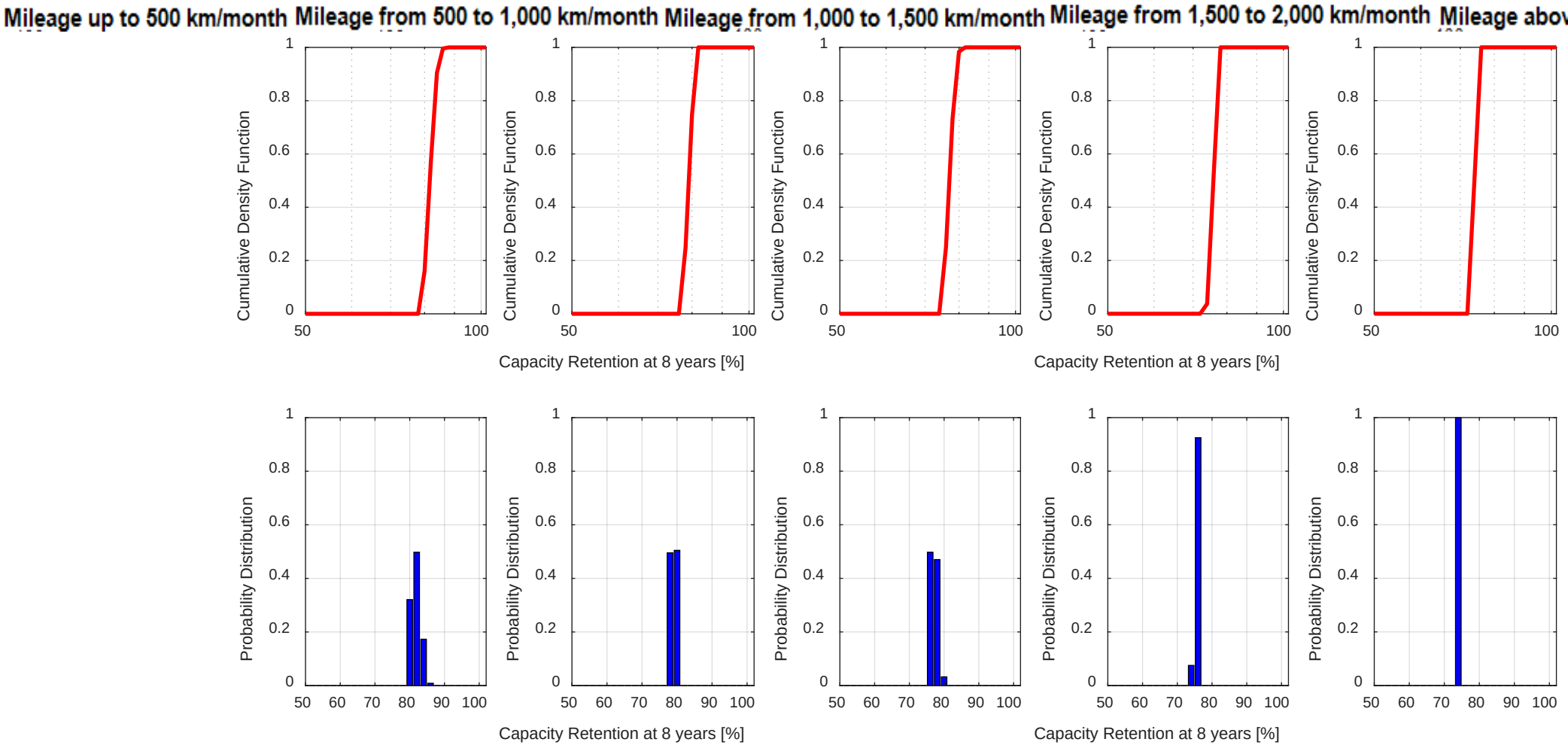


Li-Ion NCM-LMO (2015)
Modena province area

@ 7.1yrs ← v3.7yrs

European Commission

Capacity retention at 8 years - BEV-1 -Str.1 & Str. 2



>70%

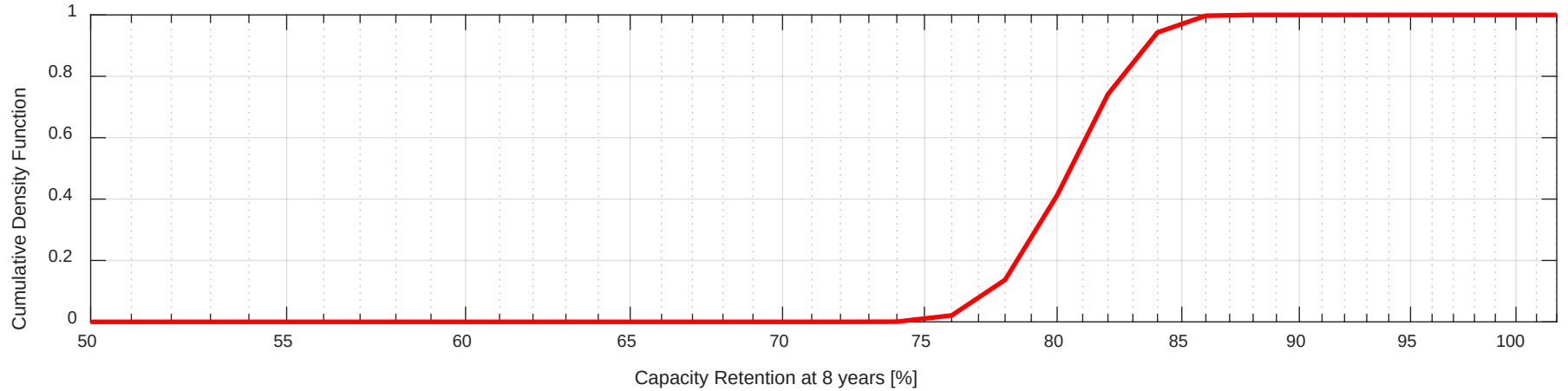
Li-Ion NCM-LMO (2015)
Modena province area

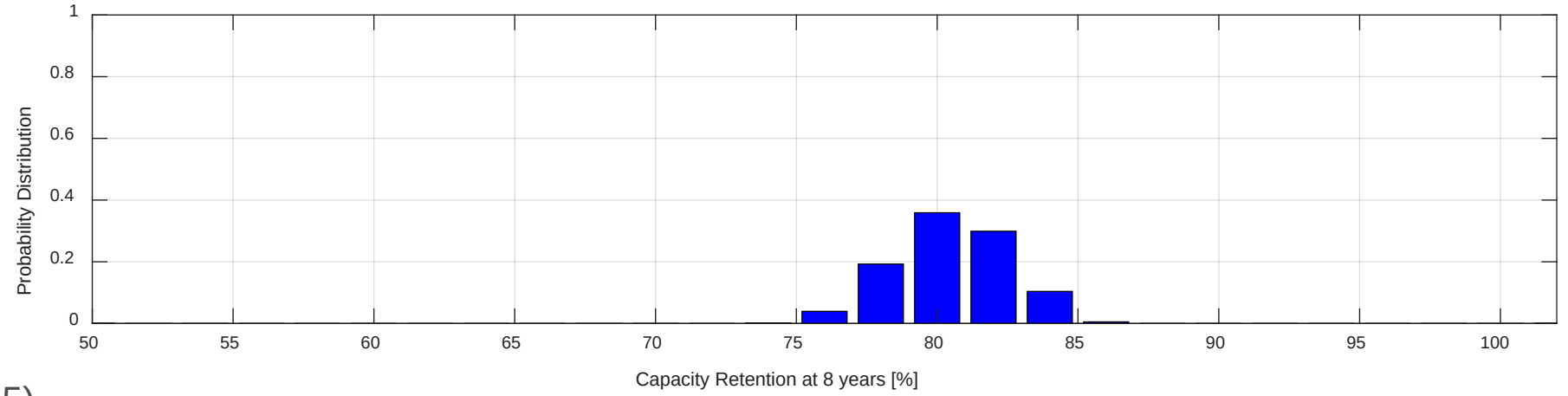
EoL 20% @ 9.3yrs | EoL 20% @ 7.9yrs | EoL 20% @ 7.1yrs | EoL 20% @ 6.6yrs | EoL 20% @ 6.2yrs

European Commission

Capacity retention at 8 years - BEV-1 Str.1&Str.2

All km/month bins distributions



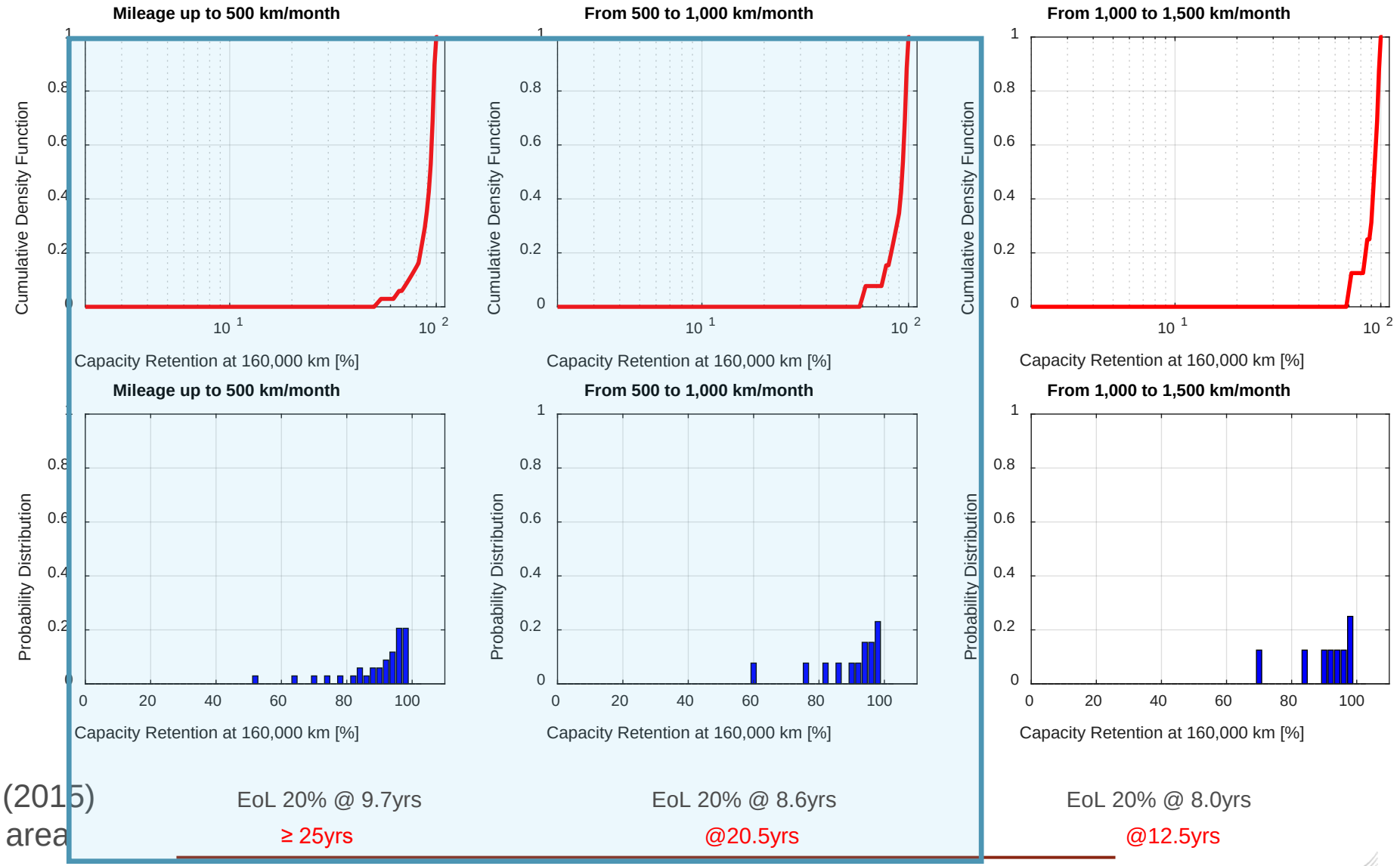


>70%

Li-Ion NCM-LMO (2015)
Modena province area

European Commission

Capacity retention at 160,000 km- BEV-1- Str. 1



>70%

Li-Ion NCM-LMO (2015)
Modena province area

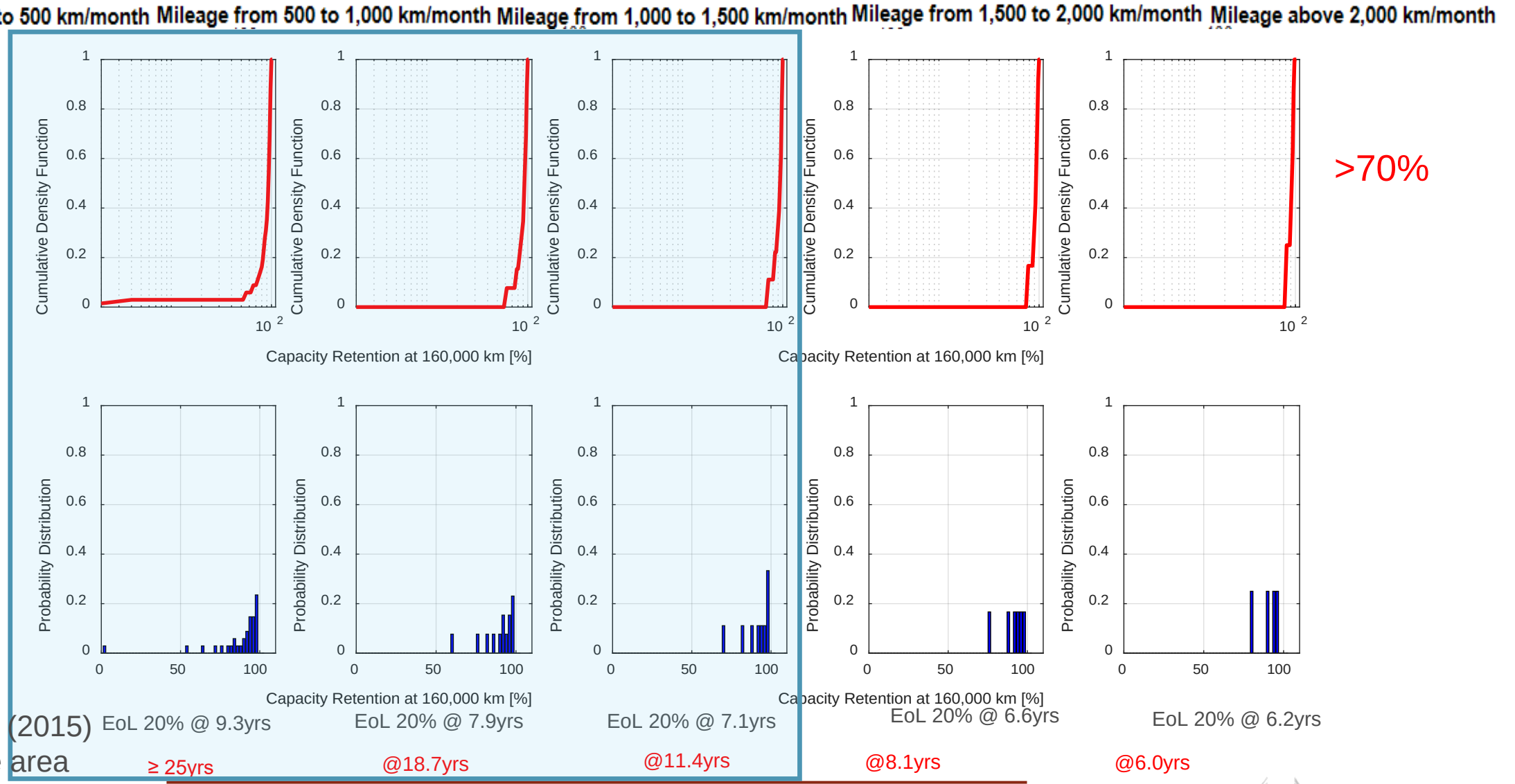
EoL 20% @ 9.7yrs
≥ 25yrs

EoL 20% @ 8.6yrs
@20.5yrs

EoL 20% @ 8.0yrs
@12.5yrs

European Commission

Capacity retention at 160,000 km- BEV-1- Str. 2



>70%

Li-Ion NCM-LMO (2015)
Modena province area

EoL 20% @ 9.3yrs ≥ 25yrs

EoL 20% @ 7.9yrs @18.7yrs

EoL 20% @ 7.1yrs @11.4yrs

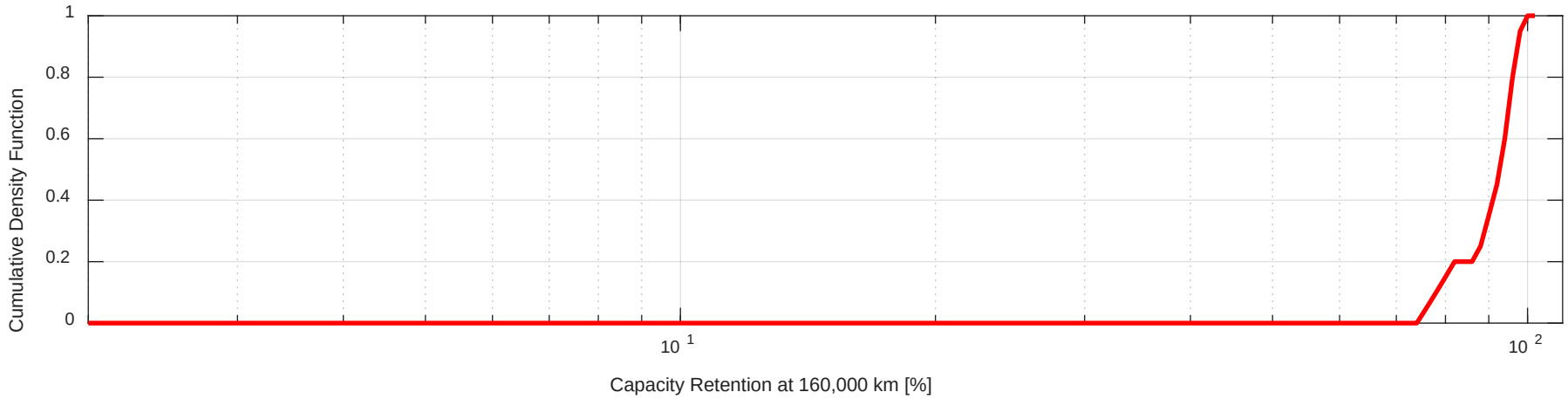
EoL 20% @ 6.6yrs @8.1yrs

EoL 20% @ 6.2yrs @6.0yrs

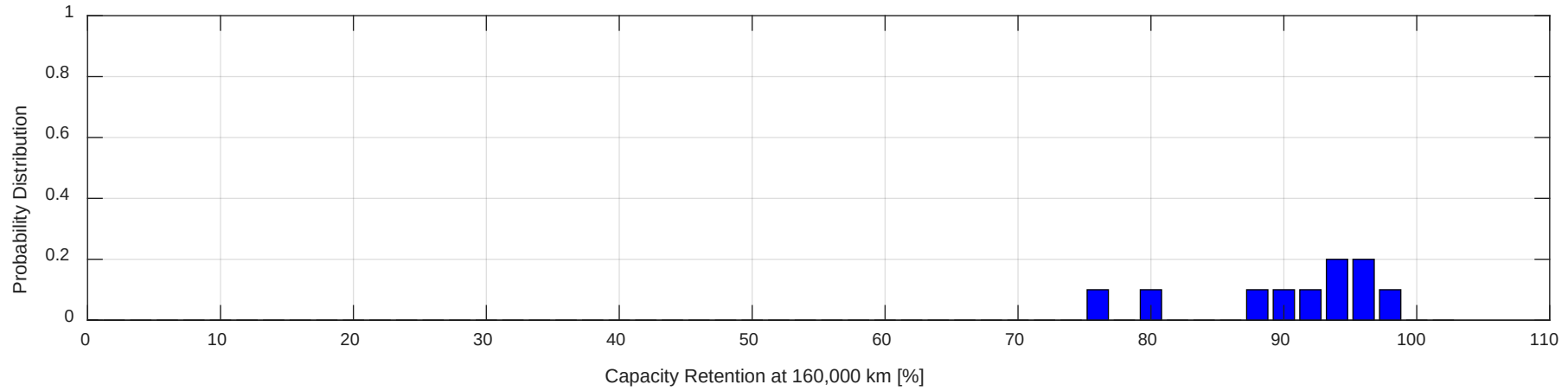
European Commission

Capacity retention at 160,000 km- BEV-1- Str. 1&Str.2

All km/month bins distributions



>70%



Li-Ion NCM-LMO (2015)
Modena province area

@ 8.1yrs ← @ 6.0yrs

European Commission

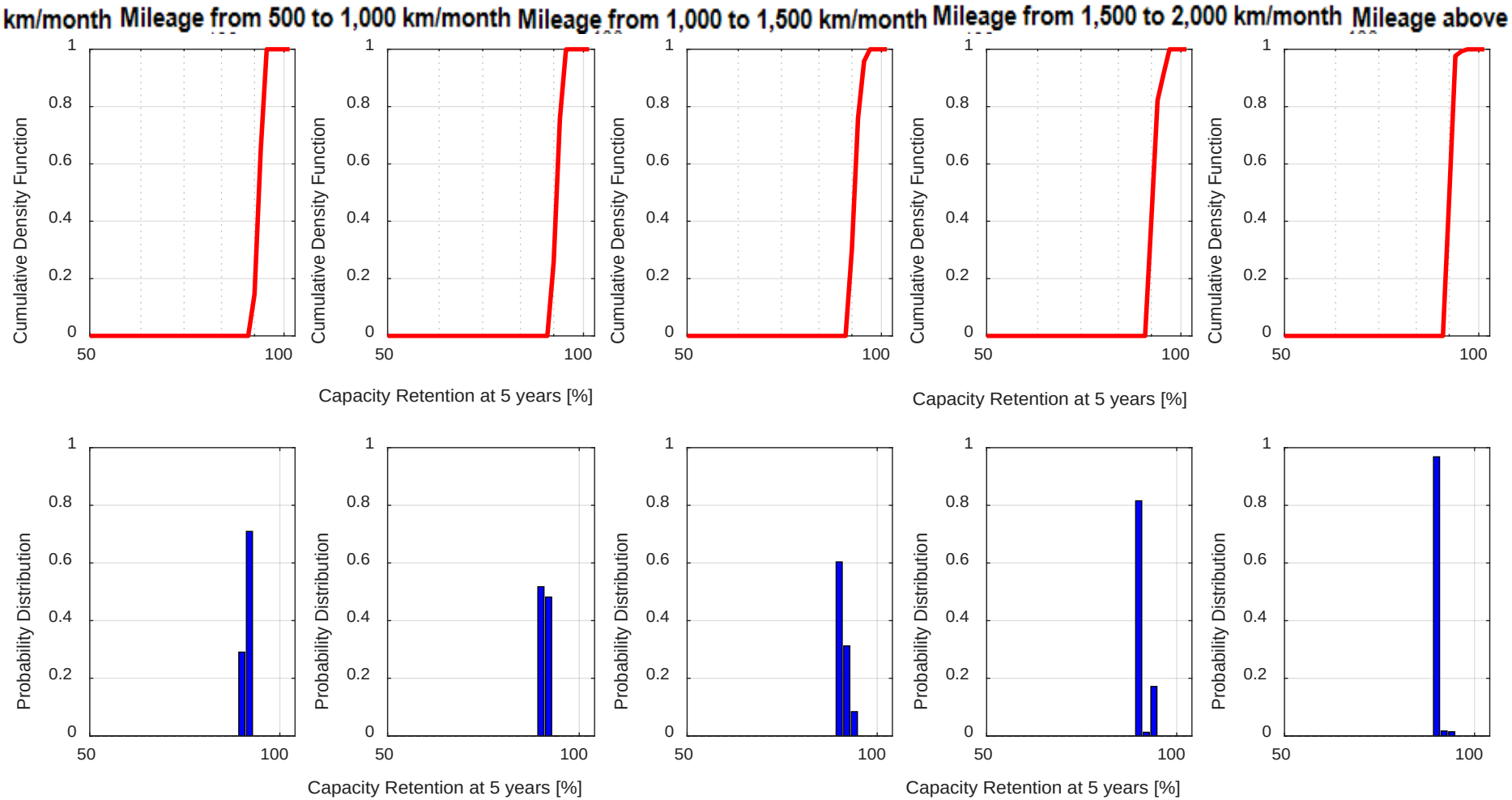
Capacity retention– BEV-2

EoL 20% @ 14.9yrs

EoL 20% @ 11.6yrs

Li-Ion NCM-LMO (2015) - Modena province area

Capacity retention at 5 years - BEV-2 – Str.1&Str.2



>90%

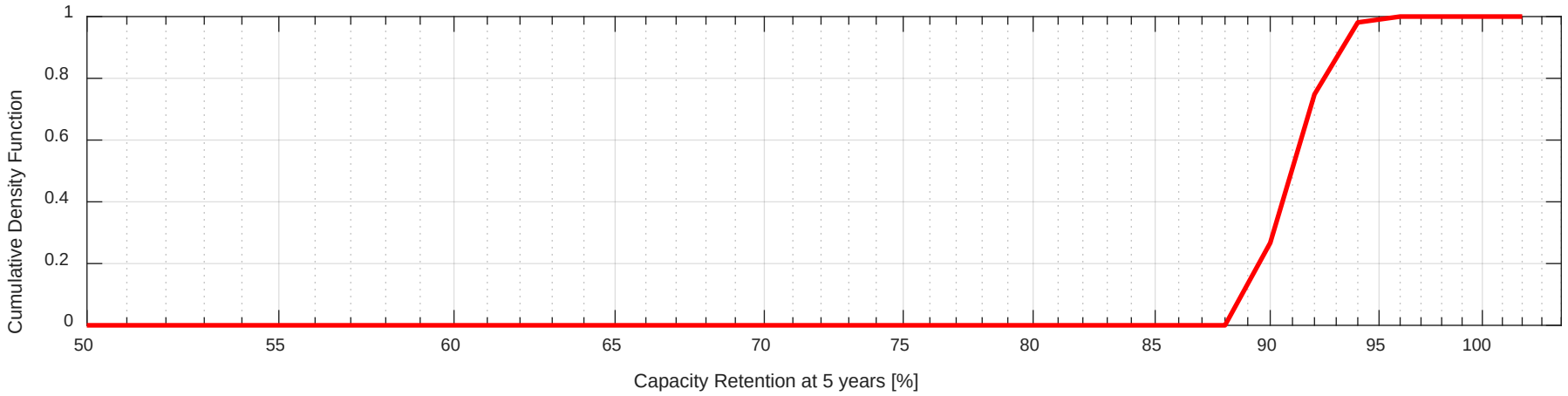
Li-Ion NCM-LMO (2015)
Modena province area

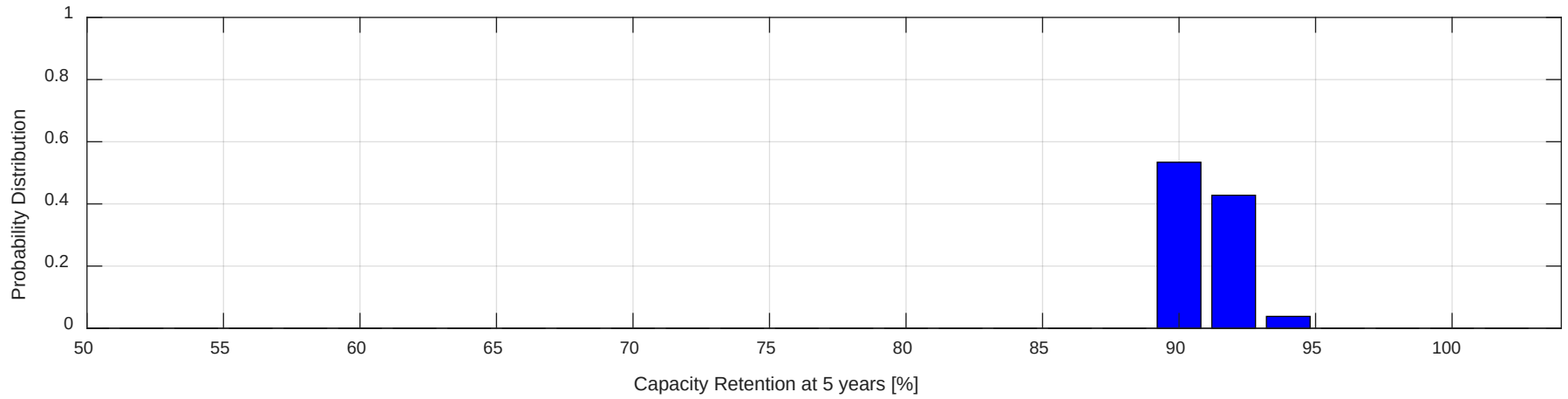
EoL 20% @ 12.1yrs | EoL 20% @ 12.7yrs | EoL 20% @ 13.6yrs | EoL 20% @ 14.7yrs | EoL 20% @ 16.1yrs

European Commission

Capacity retention at 5 years - BEV-2 Str.1&Str.2

All km/month bins distributions



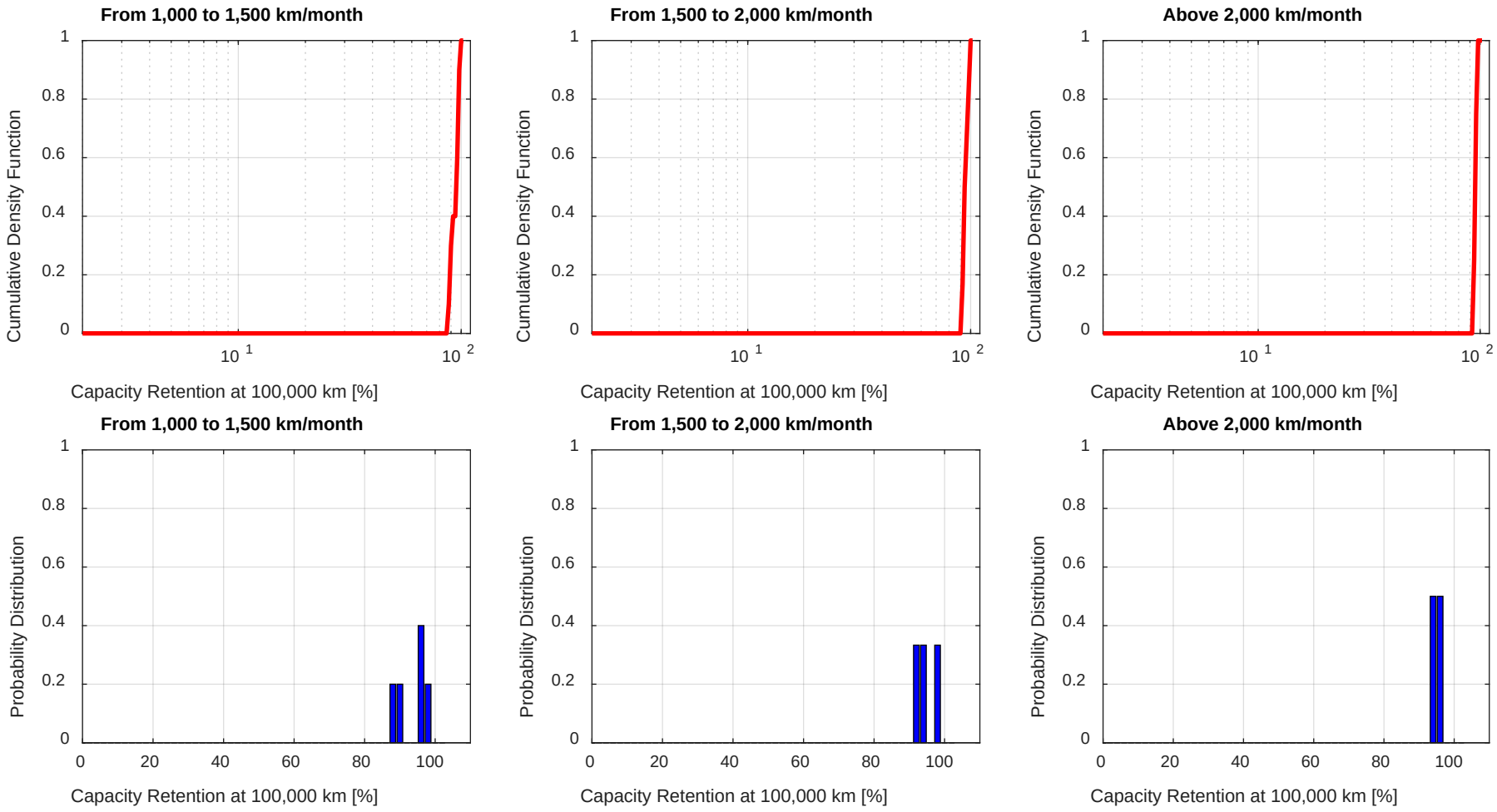


>90%

Li-Ion NCM-LMO (2015)
Modena province area

European Commission

Capacity retention at 100,000 km – BEV-2- Str.1&Str.2



>90%

Li-Ion NCM-LMO (2015)
Modena province area

EoL 20% @ 13.6yrs
@6.8yrs

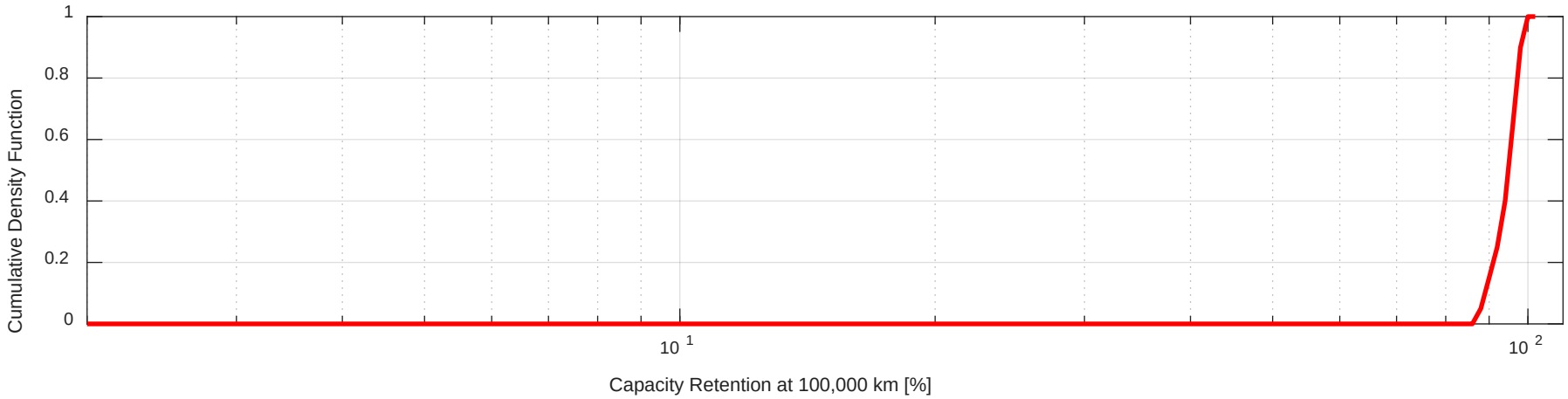
EoL 20% @ 14.7yrs
@4.8yrs

EoL 20% @ 16.1yrs
@3.4yrs

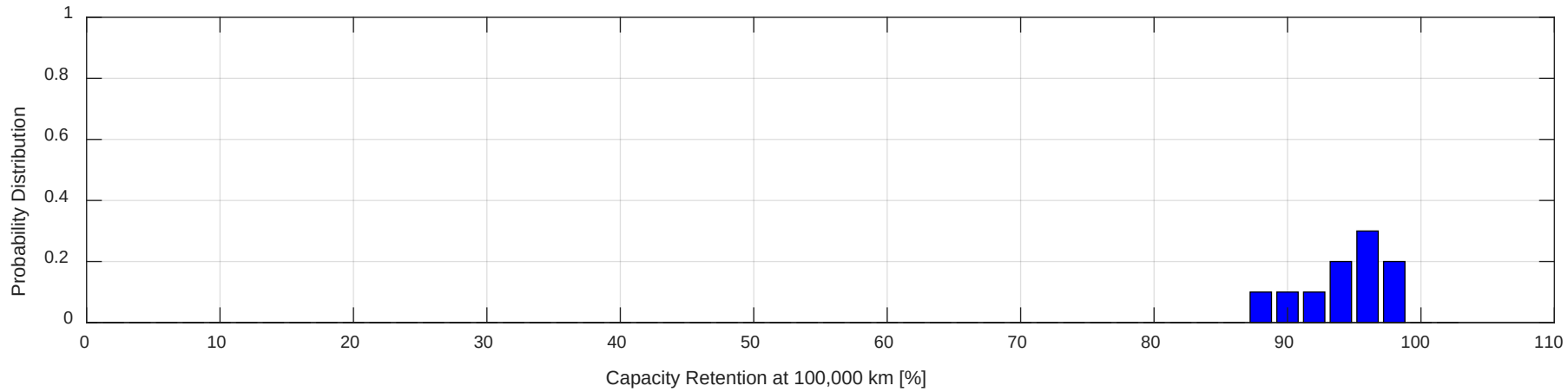
European Commission

Capacity retention at 100,000 km – BEV-2- Str.1&Str.2

All km/month bins distributions



>90%



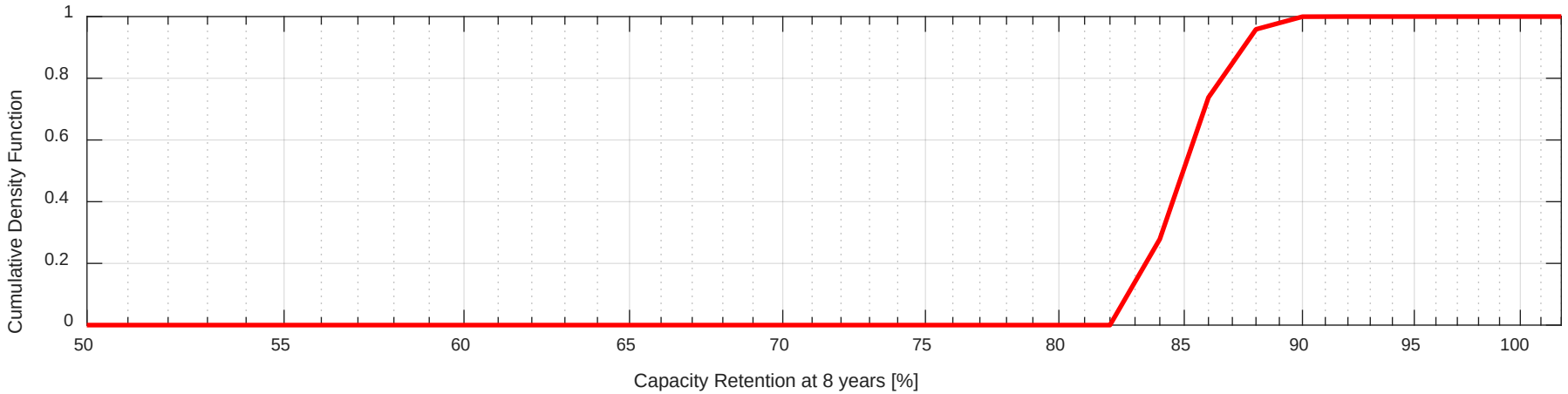
Li-Ion NCM-LMO (2015)
Modena province area

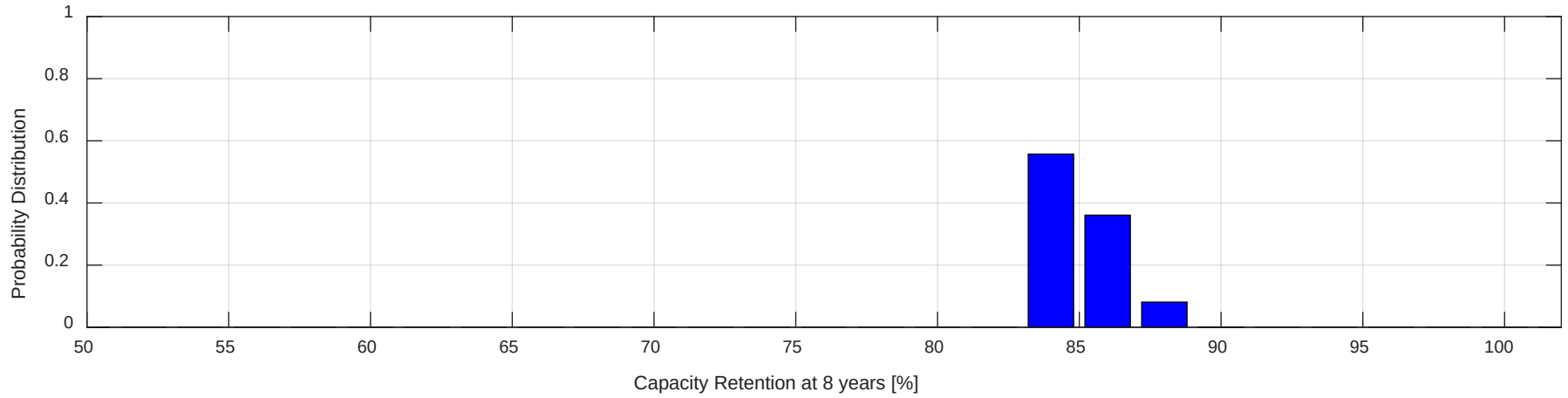
@6.8yrs ← @3.4yrs

European Commission

Capacity retention at 8 years - BEV-2 Str.1&Str.2

All km/month bins distributions





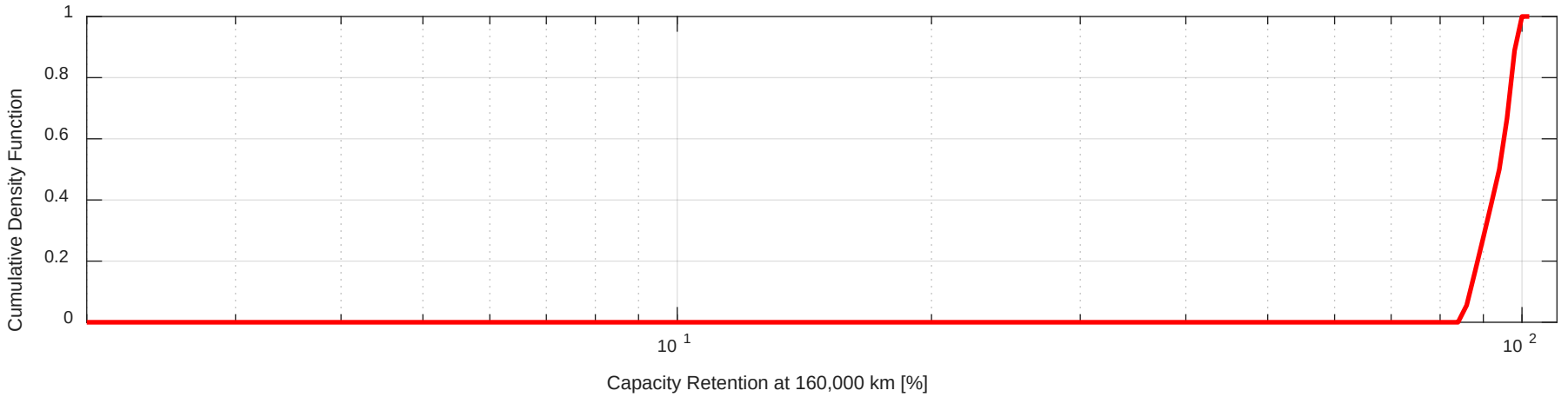
>85%

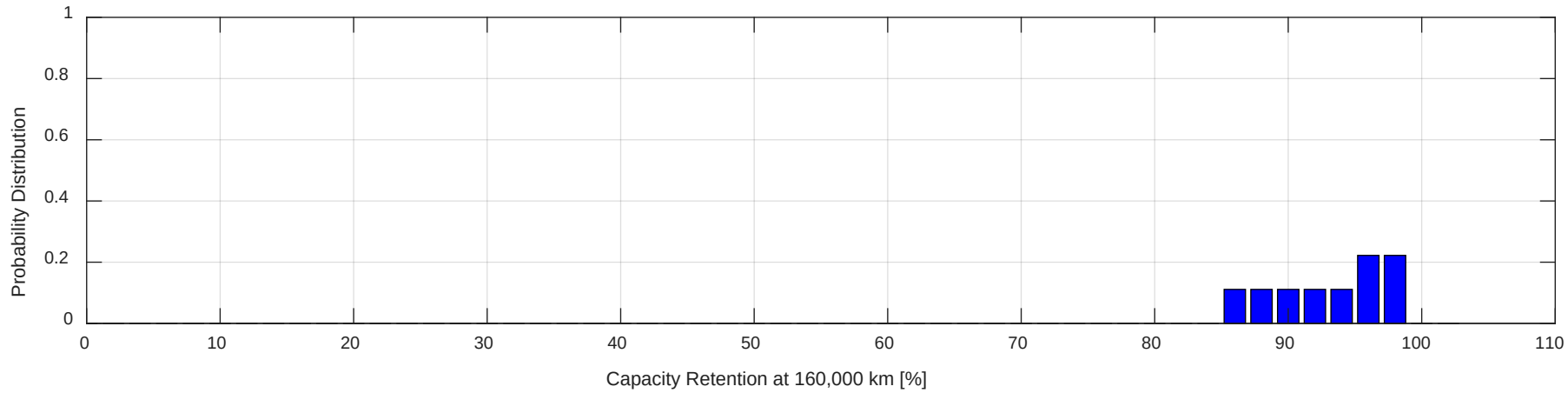
Li-Ion NCM-LMO (2015)
Modena province area

European Commission

Capacity retention at 160,000 km – BEV-2- Str.1&Str.2

All km/month bins distributions





>85%

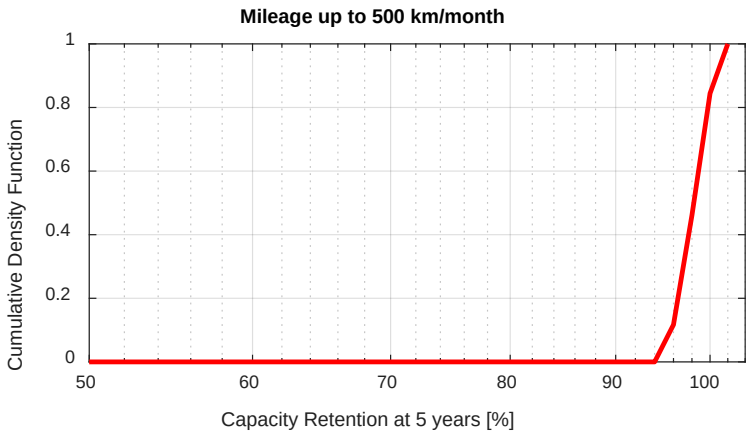
Li-Ion NCM-LMO (2015)
Modena province area

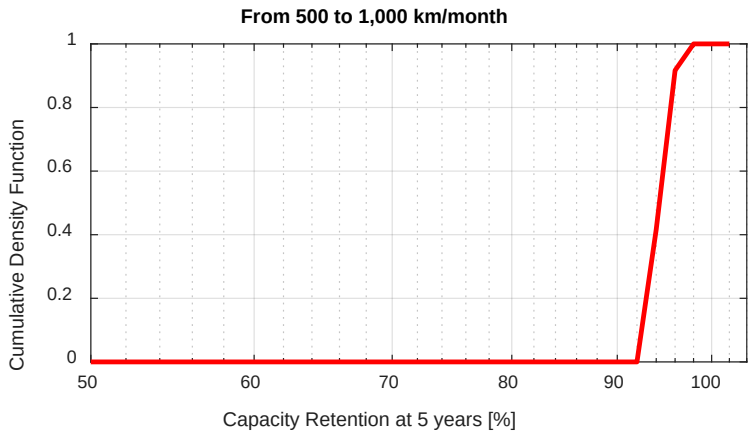
@7.7yrs ← @5.4yrs

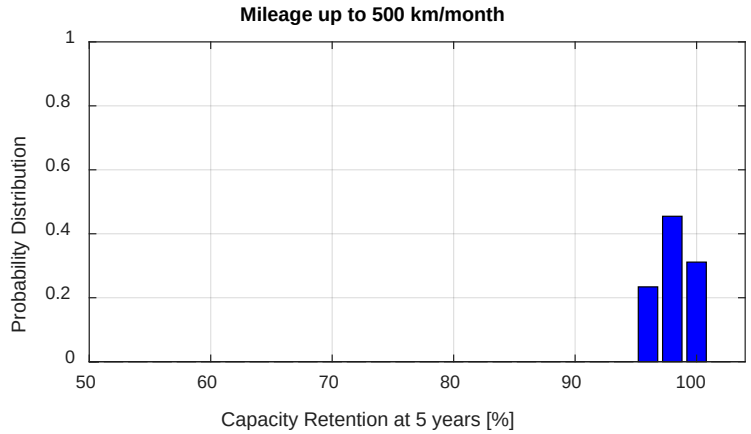
European Commission

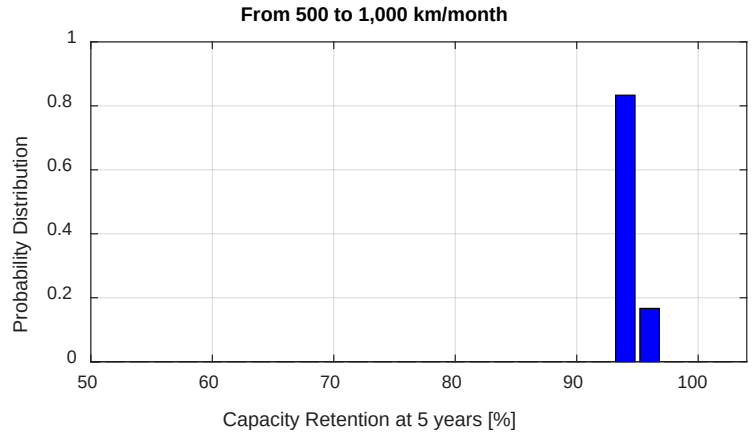
Capacity retention– PHEV- 3

Capacity retention at 5 years– PHEV -3 - Str.1









>90%

EoL 20% @ 14.9yrs

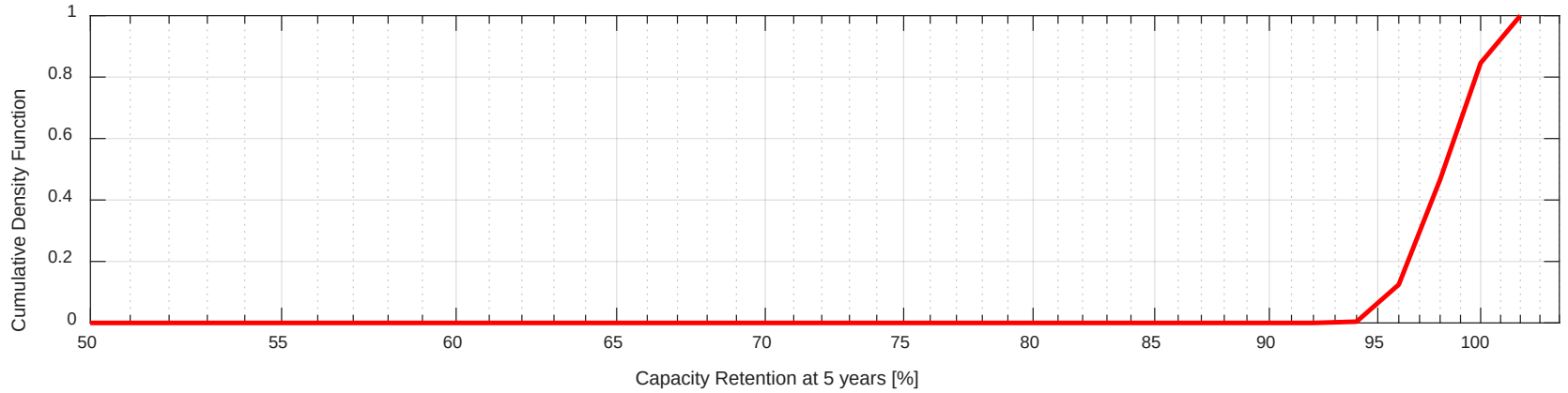
EoL 20% @ 11.6yrs

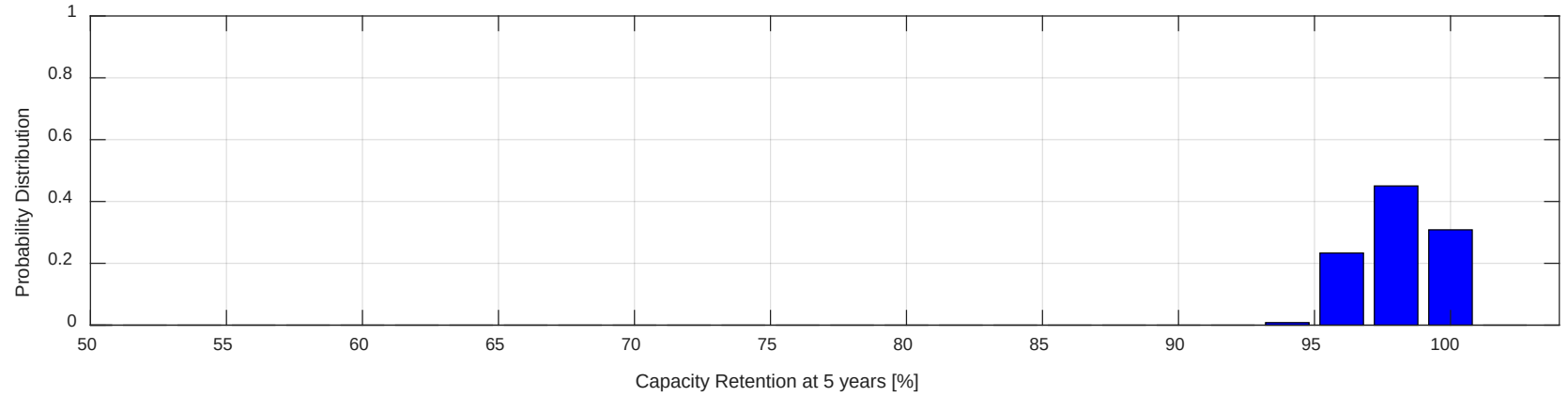
Li-Ion NCM-LMO (2015) - Modena province area

European Commission

Capacity retention at 5 years– PHEV -3 - Str.1

All km/month bins distributions





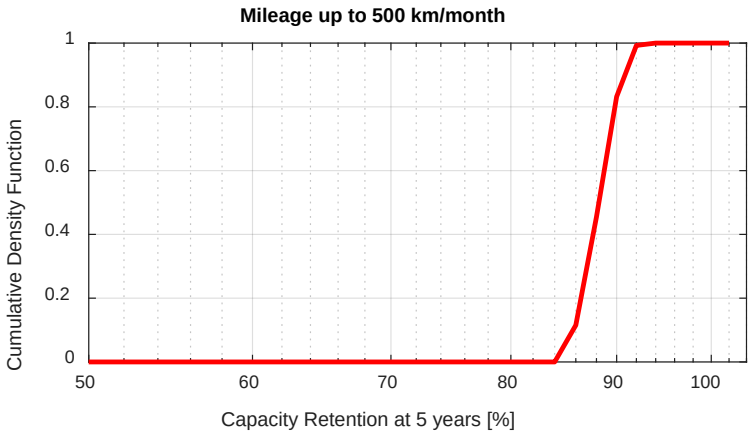
>90%

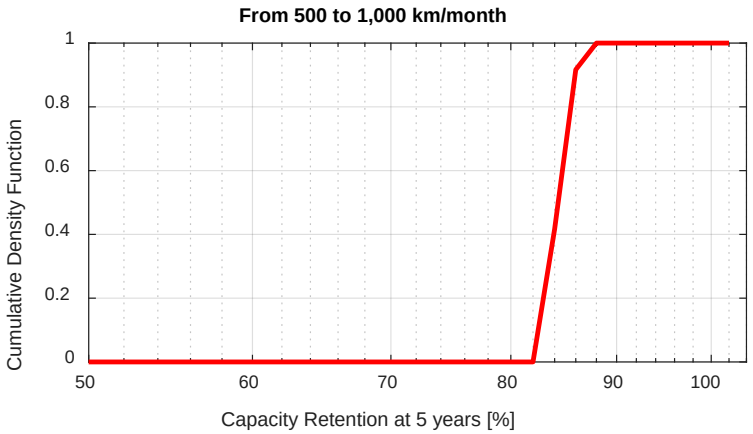
Li-Ion NCM-LMO (2015) - Modena province area

European Commission

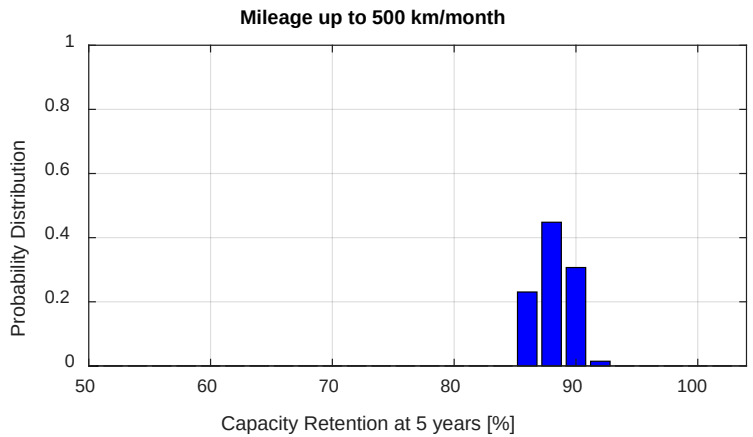
Capacity retention at 5 years– PHEV -3 - Str.1

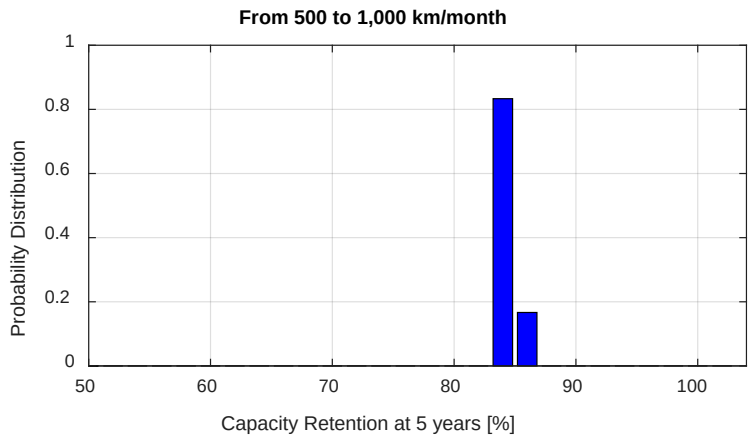
Capacity reserve 15%





>80%





EoL 20% @ 9.2yrs

EoL 20% @ 7.2yrs

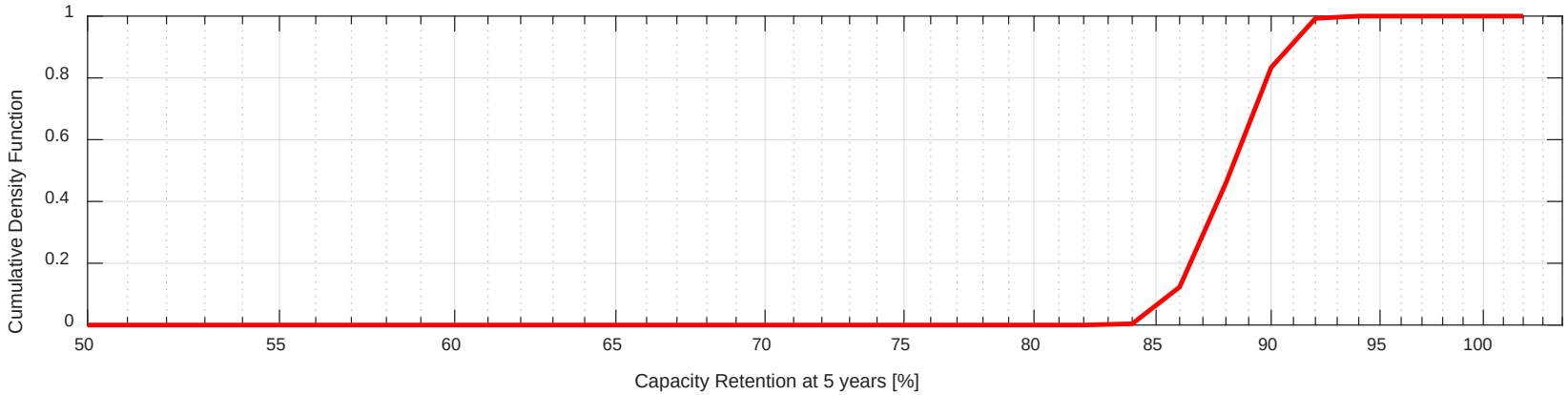
Li-Ion NCM-LMO (2015) - Modena province area

European Commission

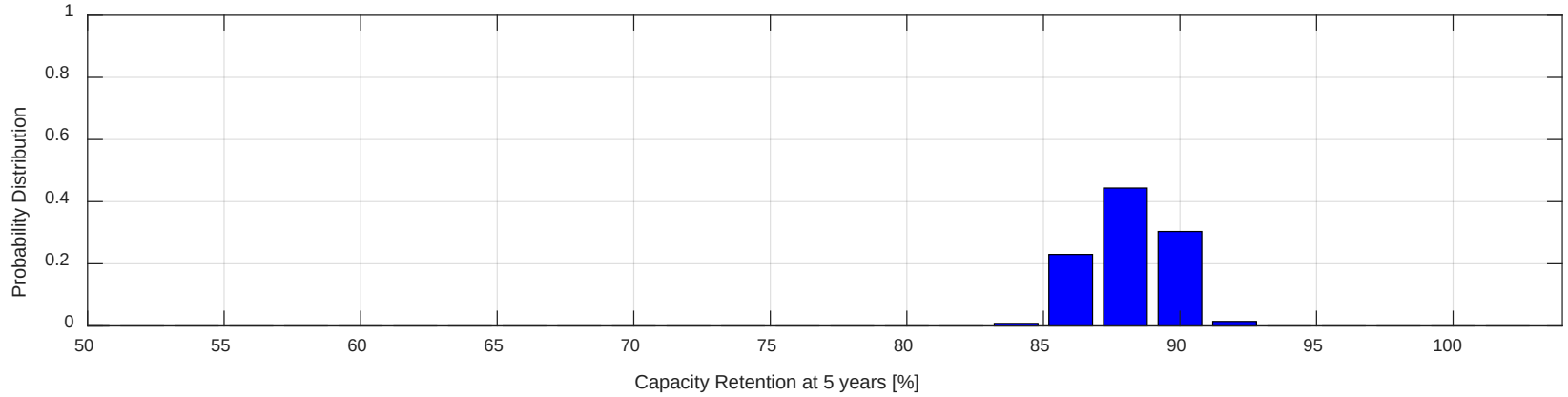
Capacity retention at 5 years– PHEV -3 - Str.1

All km/month bins distributions

Capacity reserve 15%



>80%



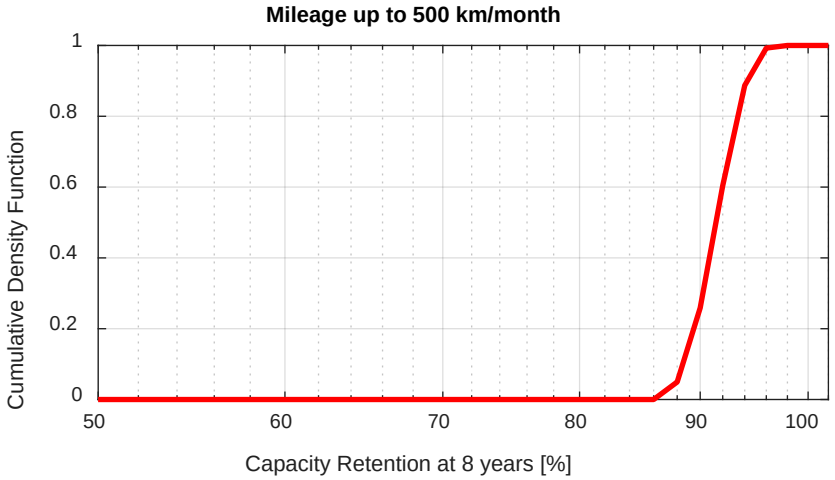
EoL 20% @ 9.2yrs

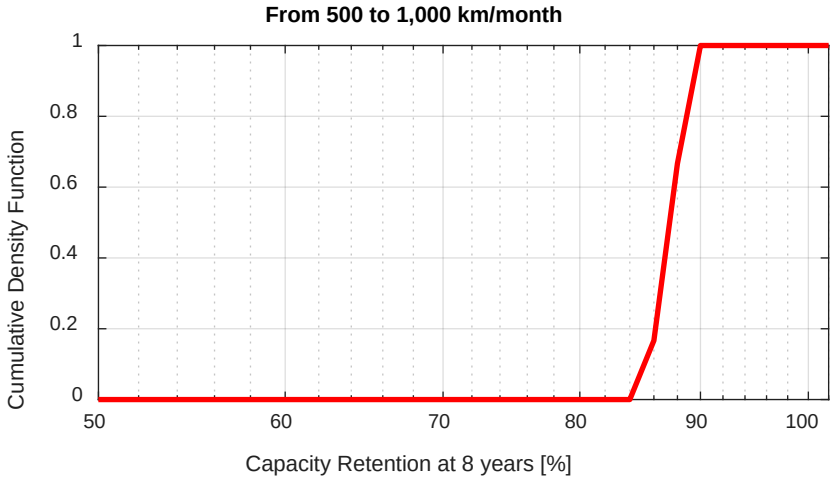
EoL 20% @ 7.2yrs

Li-Ion NCM-LMO (2015) - Modena province area

European Commission

Capacity retention at 8 years– PHEV -3 - Str.1





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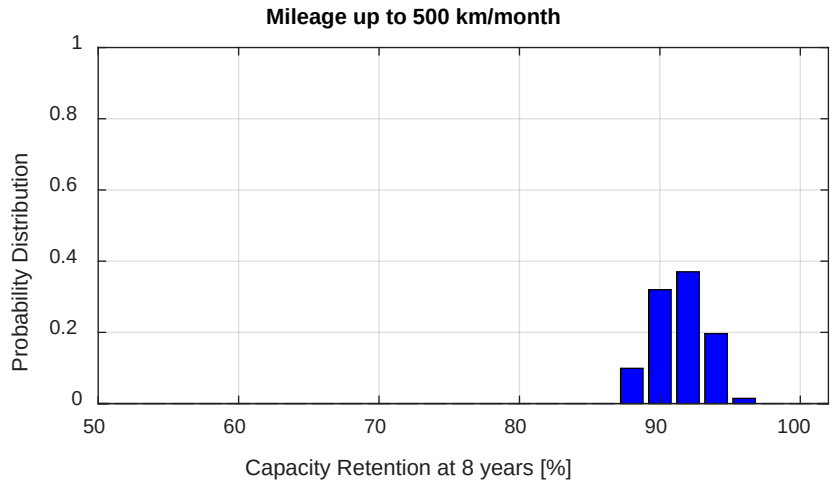
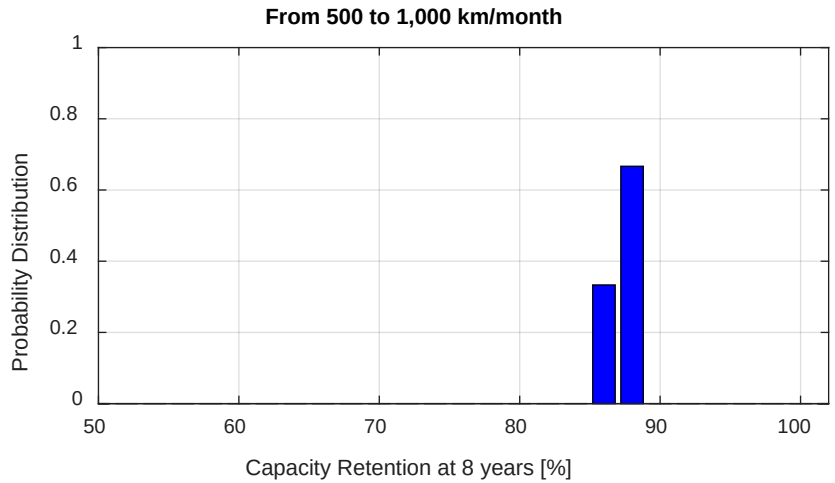


EoL 20% @ 14.9yrs



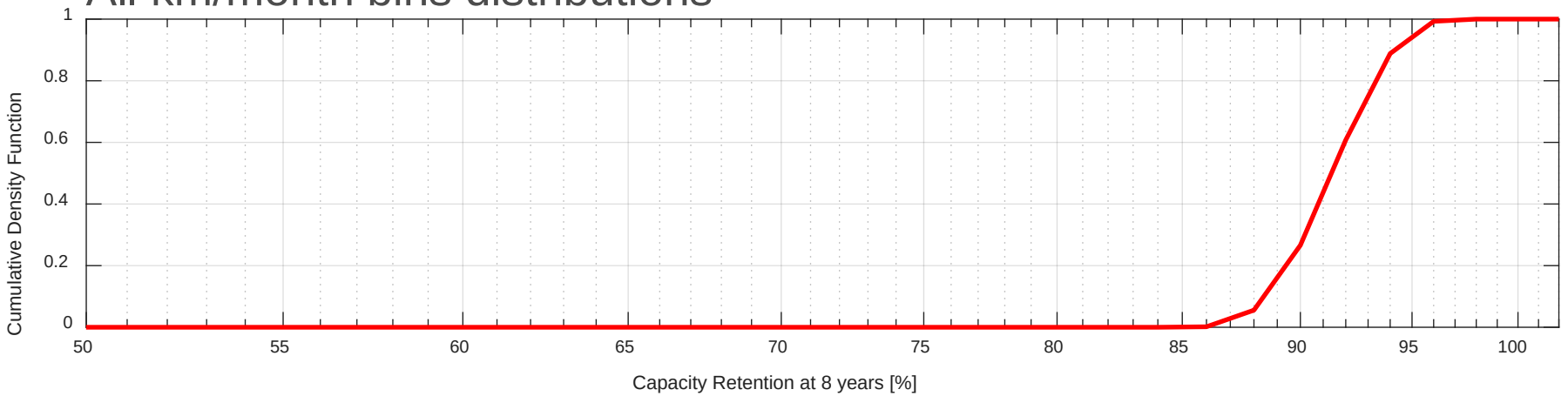
EoL 20% @ 11.6yrs

Li-Ion NCM-LMO (2015) - Modena province area

European Commission

Capacity retention at 8 years– PHEV -3 - Str.1

All km/month bins distributions



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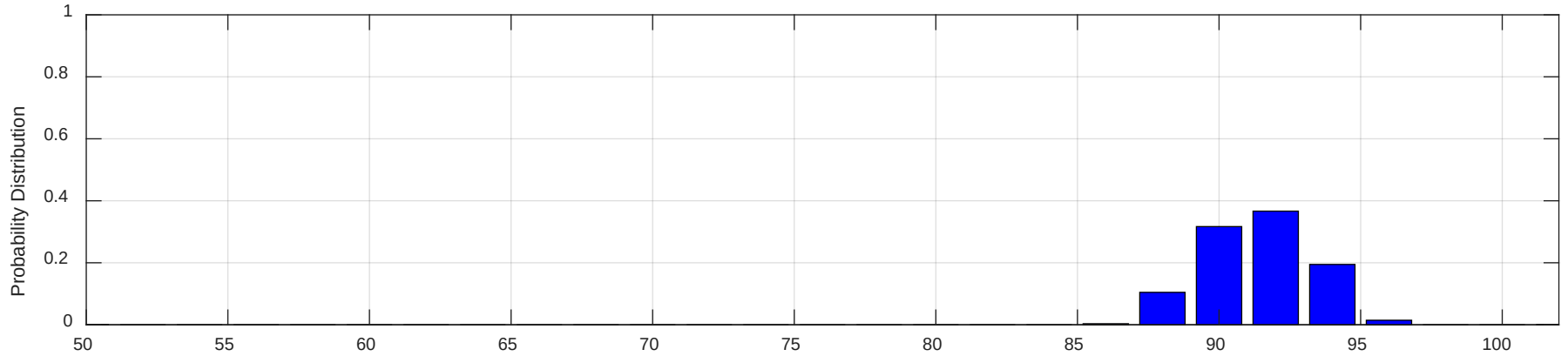


EoL 20% @ 14.9yrs

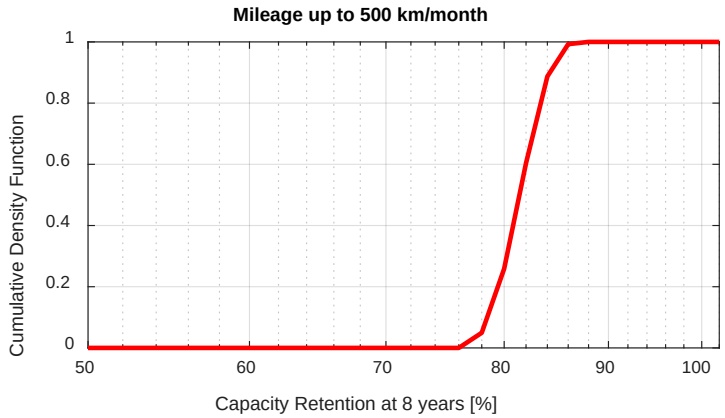
EoL 20% @ 11.6yrs

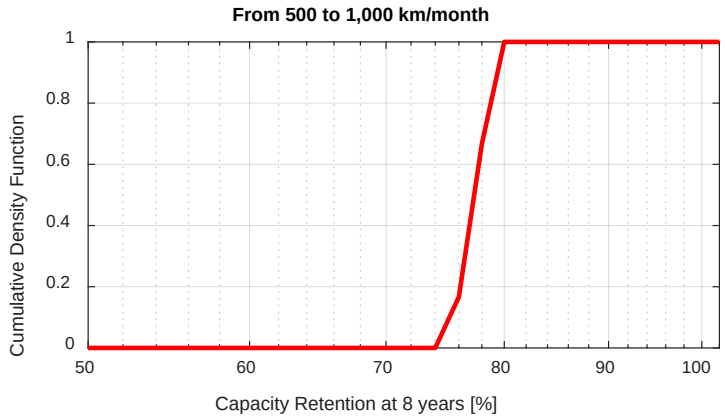
Li-Ion NCM-LMO (2015) - Modena province area

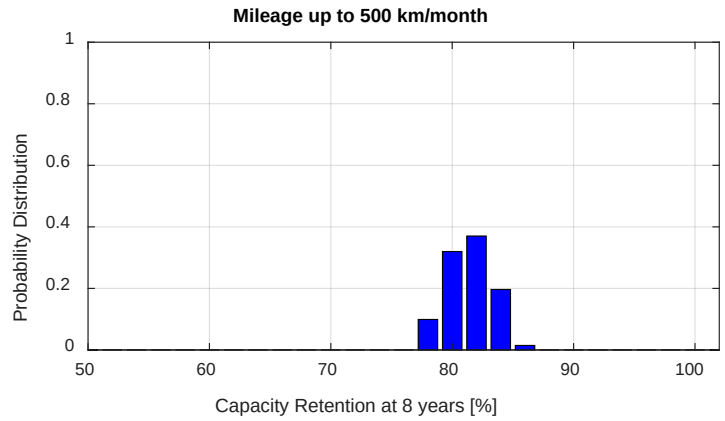
European Commission

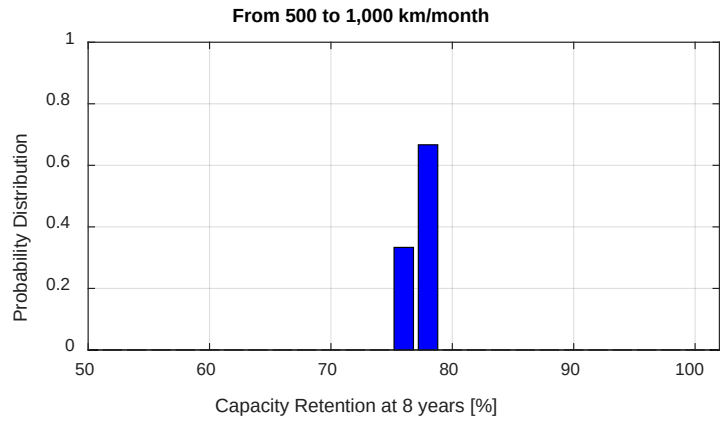
Capacity retention at 8 years– PHEV -3 - Str.1

Capacity reserve 15%









>70%

EoL 20% @ 9.2yrs

EoL 20% @ 7.2yrs

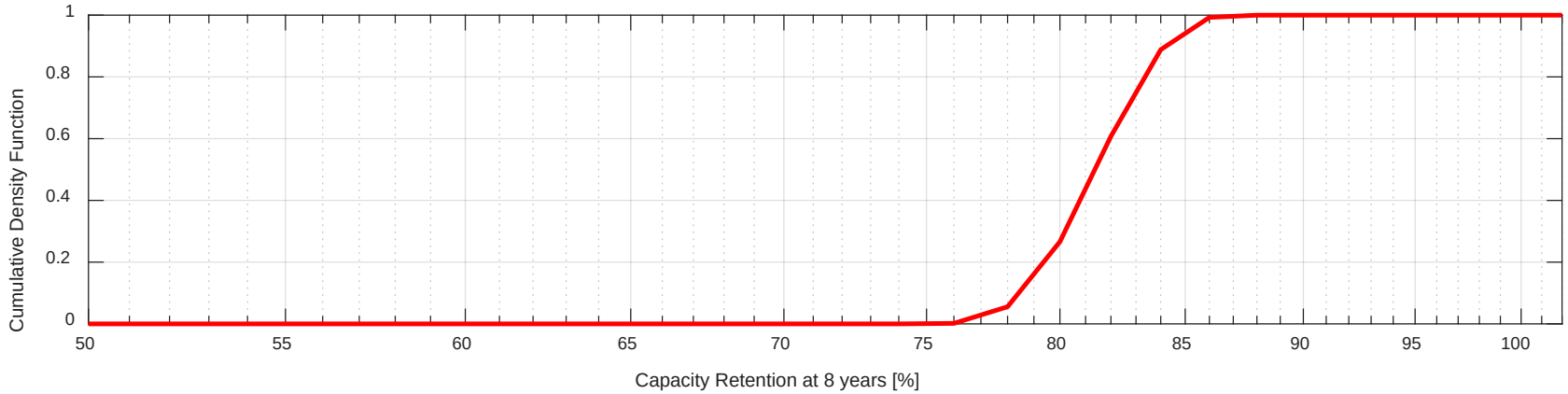
Li-Ion NCM-LMO (2015) - Modena province area

European Commission

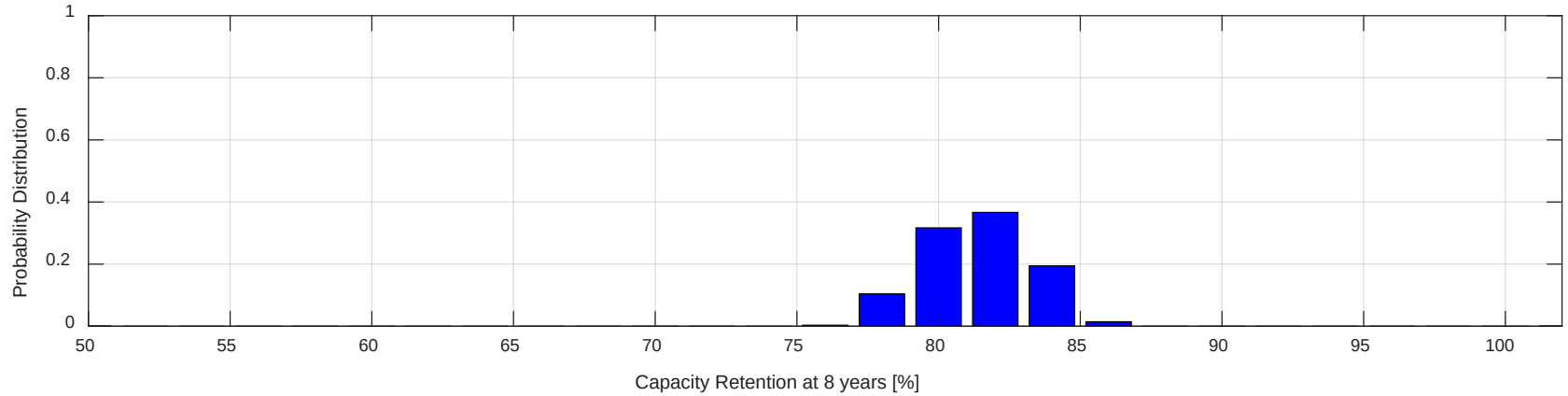
Capacity retention at 8 years– PHEV -3 - Str.1

All km/month bins distributions

Capacity reserve 15%



>70%



EoL 20% @ 9.2yrs

EoL 20% @ 7.2yrs

Li-Ion NCM-LMO (2015) - Modena province area

European Commission

PHEV analysis with reserve capacity of 15% vs 25%

- Capacity fade at 5 and 100,000km and 8 years and 160,000km

in support to the definition of the minimum performance requirements (MPR)

Capacity fade at 5 and 8 years and 100,000km and 160,000km
Capacity reserve applied: 15%BEVs, 25% PHEV

Legend
- Capacity fade above and equal 20%
- Capacity fade above or equal to 10% and below 20%;
- Capacity fade below 10%

Capacity fade in [%] at 5 years and 100,000km at 8 years and 160,000km Years Driving to Set Threshold Li-Ion NCM-LMO (2015)			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						
			5 years %	8 years %	100,000 km %	160,000 km %	Years to EoL	Years to 100,000 km	Years to 160,000 km	5 years %	8 years %	100,000 km %	160,000 km %	Years to EoL	Years to 100,000 km	Years to 160,000 km	5 years %	8 years %	100,000 km %	160,000 km %	Years to EoL	Years to 100,000 km	Years to 160,000 km	5 years %	8 years %	100,000 km %	160,000 km %	Years to EoL	Years to 100,000 km	Years to 160,000 km	5 years %	8 years %	100,000 km %	160,000 km %	Years to EoL	Years to 100,000 km	Years to 160,000 km
Recharge Strategy #1	PHEV-1			4.9	≥60	≥60	18.2	≥25	≥25		3.2	12.5	22.3	20.6	14.2	22.8																				
	BEV-1		10.2	16.9	55.2	≥60	9.7	≥25	≥25	11.7	18.7	27.6	38.8	8.6	12.8	20.5	12.4	19.5	19.3	28.3	8.2	7.9	12.6													
	BEV-2	Modena Prov.	7.5	13.5	40.0	≥60	12.1	≥25	≥25	6.9	12.7	17.8	26.4	12.7	11.2	17.9	6.2	11.8	10.0	16.5	13.6	6.9	11.1	5.4	10.8	5.5	11.0	14.7	5.0	8.1	4.6	9.7	2.3	7.0	16.1	3.9	6.3
	BEV-3		8.0	14.1	41.2	≥60	11.9	≥25	≥25	8.2	14.3	19.5	28.7	12.3	11.1	17.8	8.2	14.3	12.1	19.3	12.8	6.8	10.9	8.2	14.3	8.0	14.1	13.5	4.9	7.9	8.1	14.2	5.2	10.6	14.4	3.8	6.1
	BEV-4		9.3	15.7	22.7	≥60	10.2	≥25	≥25	10.3	17.0	22.7	32.7	9.7	11.2	17.9	10.8	17.6	15.5	23.4	9.6	6.9	11.1	11.2	18.1	11.5	18.5	9.8	5.1	8.2	11.6	18.6	8.5	14.9	10.0	3.9	6.3
Recharge Strategy #2	BEV-1		10.7	17.5	51.8	≥60	9.3	≥25	≥25	13.0	20.3	27.6	38.8	7.9	11.7	18.7	14.4	22.1	20.0	29.1	7.1	7.1	11.4	15.4	23.4	15.6	23.6	6.6	5.1	8.1	16.6	24.8	12.3	19.6	6.2	3.7	6.0
	BEV-2	Modena Prov.	8.0	14.1	41.5	≥60	11.6	≥25	≥25	8.2	14.4	19.5	28.6	11.4	11.0	17.7	8.3	14.5	12.2	19.3	11.3	6.8	10.8	8.4	14.6	8.0	14.1	11.2	4.8	7.7	8.4	14.6	4.3	9.4	11.2	3.4	5.4
	BEV-3		8.1	14.3	41.7	≥60	11.5	≥25	≥25	8.5	14.7	19.9	29.1	11.3	11.0	17.6	8.7	14.9	12.5	19.8	11.1	6.8	10.8	8.8	15.1	8.4	14.6	11.0	4.8	7.7	9.0	15.3	4.5	9.7	10.9	3.3	5.3
	BEV-4		9.4	15.9	44.9	≥60	9.8	≥25	≥25	10.6	17.4	23.0	33.1	8.6	11.0	17.7	11.4	18.4	15.7	23.8	8.0	6.8	10.8	12.1	19.2	11.6	18.6	7.5	4.8	7.8	12.8	20.1	7.8	13.9	7.1	3.4	5.4
Recharge Strategy #3	PHEV-1			4.8	42.1	≥60	18.3	≥25	≥25		2.6	9.2	18.1	21.5	12.3	19.8				3.9	30.2	7.7	12.3														
	BEV-1		10.4	17.0	50.9	≥60	9.6	≥25	≥25	11.9	18.9	25.9	36.6	8.5	11.7	18.7	12.5	19.7	17.8	26.4	8.2	7.2	11.5	12.7	20.0	13.3	20.7	8.0	5.2	8.4							
	BEV-2	Modena Prov.	7.5	13.5	40.5	≥60	12.1	≥25	≥25	6.9	12.7	17.6	26.3	12.7	11.1	17.7	6.2	11.8	9.7	16.2	13.7	6.8	10.9	5.4	10.8	5.2	10.6	14.8	4.9	7.9	4.6	9.8	2.5	7.2	16.0	4.0	6.4
	BEV-3		8.0	14.1	41.7	≥60	11.9	≥25	≥25	8.2	14.3	19.5	28.6	12.3	11.0	17.7	8.2	14.3	12.0	19.1	12.8	6.8	10.8	8.2	14.3	7.9	13.9	13.6	4.9	7.8	8.1	14.2	4.8	10.1	14.6	3.7	5.9
	BEV-4		9.3	15.7	44.8	≥60	10.2	≥25	≥25	10.3	17.0	22.6	32.5	9.7	11.1	17.7	10.9	17.7	15.2	23.1	9.6	6.8	10.9	11.2	18.1	11.2	18.1	9.8	5.0	8.0	11.5	18.5	8.9	15.4	9.9	4.1	6.6
Recharge Strategy #5	PHEV-1			6.6	41.5	≥60	16.3	≥25	≥25		8.3	15.0	25.5	13.3	11.5	18.5		9.0	6.7	15.0	14.1	7.0	11.1	2.1	9.2	1.9	9.0	13.9	4.9	7.9	2.1	9.2		5.2	13.9	3.9	6.2
	BEV-1		10.7	17.5	50.3	≥60	9.3	≥25	≥25	12.9	20.2	26.7	37.6	7.9	11.3	18.0	14.2	21.8	19.2	28.1	7.2	6.9	11.0	15.2	23.1	15.0	22.8	6.8	4.9	7.9	16.2	24.4	11.6	18.7	6.3	3.6	5.8
	BEV-2	Modena Prov.	7.9	14.0	41.7	≥60	11.7	≥25	≥25	8.0	14.1	19.1	28.1	11.6	11.0	17.6	8.0	14.0	11.7	18.7	11.6	6.8	10.8	7.9	13.9	7.5	13.4	11.7	4.8	7.7	7.6	13.6	3.2	8.1	12.0	3.3	5.2
	BEV-3		8.1	14.2	42.1	≥60	11.6	≥25	≥25	8.4	14.6	19.7	28.9	11.4	11.0	17.6	8.6	14.8	12.4	19.7	11.4	6.8	10.8	8.7	15.0	8.3	14.5	11.4	4.8	7.7	8.8	15.1	4.1	9.2	11.5	3.2	5.1
	BEV-4		9.4	15.8	45.2	≥60	9.9	≥25	≥25	10.6	17.3	22.9	32.9	8.8	11.0	17.6	11.3	18.3	15.6	23.6	8.3	6.8	10.8	11.9	19.0	11.5	18.5	7.9	4.8	7.7	12.7	19.9	7.3	13.3	7.5	3.3	5.2

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Capacity fade at 5 and 8 years and 100,000km and 160,000km
No capacity reserve applied

Legend
- Capacity fade above and equal 20%
- Capacity fade above or equal to 10% and below 20%;

Capacity fade in [%] No Reserve **at 5 years and 100,000km** **at 8 years and 160,000km** Years Driving to Set Threshold Li-Ion NCM-LMO (2015)			0 - 500 km/month							500 – 1,000 km/month						
			5 years %	8 years %	100,000 km %	160,000 km %	Years to EoL	Years to 100,000 km	Years to 160,000 km	5 years %	8 years %	100,000 km %	160,000 km %	Years to EoL	Years to 100,000 km	Years to 160,000 km
Recharge Strategy #1	PHEV-1	Modena Prov.	24.8	35.1	≥ 60	≥ 60	3.2	≥ 25	≥ 25	26.5	37.3	43.8	58.3	2.8	14.2	22.8
	BEV-1		25.2	35.6	≥ 60	≥ 60	3.1	≥ 25	≥ 25	26.7	37.7	42.1	54.0	2.8	12.8	20.5
	BEV-2		22.5	31.9	≥ 60	≥ 60	3.9	≥ 25	≥ 25	21.9	31.0	32.6	40.8	4.2	11.2	17.9
	BEV-3															
	BEV-4															
Recharge Strategy #2	BEV-1	Modena Prov.	25.7	36.3	≥ 60	≥ 60	3.0	≥ 25	≥ 25	28.0	39.4	42.3	53.2	2.5	11.7	18.7
	BEV-2		23.0	32.5	≥ 60	≥ 60	3.8	≥ 25	≥ 25	23.2	32.8	34.4	43.0	3.7	11.0	17.7
	BEV-3															
	BEV-4															
Recharge Strategy #3	PHEV-1	Modena Prov.	25.1	35.5	≥ 60	≥ 60	3.2	≥ 25	≥ 25	26.6	37.6	41.3	52.5	2.8	12.3	19.8
	BEV-1		25.4	35.8	≥ 60	≥ 60	3.1	≥ 25	≥ 25	26.9	37.9	40.6	51.0	2.8	11.7	18.7
	BEV-2		22.5	31.9	≥ 60	≥ 60	3.9	≥ 25	≥ 25	21.9	31.0	32.5	40.7	4.2	11.1	17.7
	BEV-3															
	BEV-4															
Recharge Strategy #5	PHEV-1	Modena Prov.	25.5	36.1	≥ 60	≥ 60	3.1	≥ 25	≥ 25	27.7	39.0	41.7	52.3	2.6	11.5	18.5
	BEV-1		25.7	36.3	≥ 60	≥ 60	3.0	≥ 25	≥ 25	27.9	39.3	41.5	51.9	2.6	11.3	18.0
	BEV-2		22.9	32.4	≥ 60	≥ 60	3.8	≥ 25	≥ 25	23.0	32.5	34.0	42.5	3.8	11.0	17.6
	BEV-3															
	BEV-4															

Capacity fade in [%] No Reserve **at 5 years and 100,000km** **at 8 years and 160,000km** Years Driving to Set Threshold Li-Ion NCM-LMO (2015)			1,000 -1,500 km/month							1,500 – 2,000 km/month							2,000+ km/month						
			5 years %	8 years %	100,000 km %	160,000 km %	Years to EoL	Years to 100,000 km	Years to 160,000 km	5 years %	8 years %	100,000 km %	160,000 km %	Years to EoL	Years to 100,000 km	Years to 160,000 km	5 years %	8 years %	100,000 km %	160,000 km %	Years to EoL	Years to 100,000 km	Years to 160,000 km
Recharge Strategy #1	PHEV-1	Modena Prov.																					
	BEV-1		27.4	38.6	34.4	42.8	2.7	7.9	12.6														
	BEV-2		21.2	30.0	25.1	31.4	4.4	6.9	11.1	20.4	28.9	20.5	26.1	4.8	5.0	8.1	19.6	27.6	17.3	22.1	5.2	3.9	6.3
	BEV-3																						
	BEV-4																						
Recharge Strategy #2	BEV-1	Modena Prov.	29.4	41.4	35.1	43.9	2.3	7.1	11.4	30.4	42.9	30.6	38.8	2.1	5.1	8.1	31.6	44.5	27.3	34.6	2.0	3.7	6.0
	BEV-2		21.2	30.0	25.1	34.2	3.7	6.8	10.8	23.4	33.1	23.0	29.3	3.6	4.8	7.7	23.4	33.1	19.2	24.4	3.6	3.4	5.4
	BEV-3																						
	BEV-4																						
Recharge Strategy #3	PHEV-1	Modena Prov.	27.3	38.5	33.9	42.2	2.7	7.7	12.3														
	BEV-1		27.5	38.7	33.0	41.2	2.6	7.2	11.5	27.7	39.0	28.3	35.9	2.6	5.2	8.4							
	BEV-2		21.2	29.9	24.8	31.1	4.5	6.8	10.9	20.4	28.8	20.2	25.7	4.8	4.9	7.9	19.6	27.7	17.5	22.2	5.2	4.0	6.4
	BEV-3																						
	BEV-4																						
Recharge Strategy #5	PHEV-1	Modena Prov.	29.0	40.9	34.3	42.9	2.4	7.0	11.1	30.0	42.3	29.8	37.8	2.2	4.9	7.9	30.8	43.4	27.1	34.4	2.1	3.9	6.2
	BEV-1		29.2	41.1	34.3	42.9	2.3	6.9	11.0	30.2	42.5	30.0	38.0	2.2	4.9	7.9	31.2	44.0	26.6	33.7	2.0	3.6	5.8
	BEV-2		23.0	32.4	26.8	33.6	3.8	6.8	10.8	22.9	32.3	22.5	28.6	3.8	4.8	7.7	22.6	32.0	18.2	23.1	3.9	3.3	5.2
	BEV-3																						
	BEV-4																						

Capacity fade at 5 and 8 years and 100,000km and 160,000km
15% capacity reserve applied to PHEVs

Legend
- Capacity fade above and equal 20%
- Capacity fade above or equal to 10% and below 20%;
- Capacity fade below 10%

Capacity fade in [%] Reserve 15% **at 5 years and 100,000km at 8 years and 160,000km** Years Driving to Set Threshold Li-Ion NCM-LMO (2015)			0 - 500 km/month							500 – 1,000 km/month						
			5 years %	8 years %	100,000 km %	160,000 km %	Years to EoL	Years to 100,000 km	Years to 160,000 km	5 years %	8 years %	100,000 km %	160,000 km %	Years to EoL	Years to 100,000 km	Years to 160,000 km
Recharge Strategy #1	PHEV-1	Modena Prov.	9.8	20.1	≥ 60	≥ 60	10.0	≥ 25	≥ 25	11.5	22.3	28.8	43.3	8.8	14.2	22.8
	PHEV-2		10.0	20.4	≥ 60	≥ 60	9.8	≥ 25	≥ 25	13.1	24.6	30.6	44.7	7.8	13.7	21.9
	PHEV-3		10.8	21.4	≥ 60	≥ 60	9.2	≥ 25	≥ 25	14.2	26.1	32.1	46.3	7.2	13.5	21.6
Recharge Strategy #3	PHEV-1	Modena Prov.	10.1	20.5	≥ 60	≥ 60	9.7	≥ 25	≥ 25	11.6	22.6	26.3	37.5	8.7	12.3	19.8
	PHEV-2		10.6	21.1	≥ 60	≥ 60	9.4	≥ 25	≥ 25	13.0	24.5	31.0	45.9	7.8	14.0	22.4
	PHEV-3		11.4	22.2	≥ 60	≥ 60	8.8	≥ 25	≥ 25	14.2	26.1	32.1	46.3	7.2	13.5	21.6
Recharge Strategy #4	PHEV-1	Modena Prov.	10.1	20.4	≥ 60	≥ 60	9.8	≥ 25	≥ 25	11.6	22.5	27.2	39.4	8.7	13.0	20.8
	PHEV-2		10.6	21.1	≥ 60	≥ 60	9.4	≥ 25	≥ 25	13.1	24.6	30.7	44.9	7.8	13.7	22
	PHEV-3		11.4	22.2	≥ 60	≥ 60	8.8	≥ 25	≥ 25	14.2	26.1	32.1	46.3	7.2	13.5	21.6
Recharge Strategy #5	PHEV-1	Modena Prov.	10.5	21.1	≥ 60	≥ 60	9.4	≥ 25	≥ 25	12.7	24.0	26.7	37.3	8.0	11.5	18.5
	PHEV-2		11.1	21.9	≥ 60	≥ 60	9.0	≥ 25	≥ 25	14.2	26.1	29.5	41.2	7.2	11.9	19.1
	PHEV-3		12.0	23.0	≥ 60	≥ 60	8.5	36.07	57.72	15.5	28.0	31.2	43.2	6.6	11.8	18.8

Capacity fade in [%] Reserve 15% **at 5 years and 100,000km at 8 years and 160,000km** Years Driving to Set Threshold Li-Ion NCM-LMO (2015)			1,000 -1,500 km/month							1,500 – 2,000 km/month							2,000+ km/month						
			5 years %	8 years %	100,000 km %	160,000 km %	Years to EoL	Years to 100,000 km	Years to 160,000 km	5 years %	8 years %	100,000 km %	160,000 km %	Years to EoL	Years to 100,000 km	Years to 160,000 km	5 years %	8 years %	100,000 km %	160,000 km %	Years to EoL	Years to 100,000 km	Years to 160,000 km
Recharge Strategy #1	PHEV-1	Modena Prov.																					
	PHEV-2																						
	PHEV-3																						
Recharge Strategy #3	PHEV-1	Modena Prov.	12.3	23.5	18.9	27.2	8.3	7.7	12.3														
	PHEV-2																						
	PHEV-3																						
Recharge Strategy #4	PHEV-1	Modena Prov.																					
	PHEV-2																						
	PHEV-3																						
Recharge Strategy #5	PHEV-1	Modena Prov.	14.0	25.9	19.3	27.9	7.3	7.0	11.1	15.0	27.3	14.8	22.8	6.8	4.9	7.9	15.8	28.4	12.1	19.4	6.5	3.9	6.2
	PHEV-2		16.0	28.6	22.0	31.3	6.4	7.1	11.4	17.3	30.5	17.7	26.3	5.9	5.1	8.2							
	PHEV-3		17.7	31.0	23.7	33.4	5.8	7.0	11.2	19.3	33.3	19.2	28.4	5.2	5.0	8.0							

Minimum performance requirements (PR) – JRC TEMA

- Minimum performance requirement according to the analysis of **all possible vehicles, battery architectures, mileage and recharging strategies as for** JRC TEMA analyses:

  - **BEV: > 80% of certified capacity within 5 year or 100,000 km**

    > 70% of certified capacity within 8 year or 160,000 km

  - **PHEV: > 90% of certified capacity within 5 year or 100,000 km**

    > 80% of certified capacity within 8 year or 160,000 km

  No capacity reserve 0%

  - BEV: > 70% of certified capacity within 5 year or 100,000 km

    > 60% of certified capacity within 8 year or 160,000 km

  - PHEV: > 70% of certified capacity within 5 year or 100,000 km

    > 55% of certified capacity within 8 year or 160,000 km

  PHEV capacity reserve 15% as BEV

  - PHEV: > 80% of certified capacity within 5 year or 100,000 km

    > 70% of certified capacity within 8 year or 160,000 km

Minimum performance requirements (PR) – JRC TEMA

- Minimum performance requirement according to the analysis of the **advanced vehicles, battery architectures as for** JRC TEMA analyses:
  - BEV: > 90% of certified capacity within 5 year or 100,000 km
    > 85% of certified capacity within 8 year or 160,000 km
  - PHEV: > 95% of certified capacity within 5 year or 100,000 km
    > 90% of certified capacity within 8 year or 160,000 km

  No capacity reserve 0%

  - BEV: > 75% of certified capacity within 5 year or 100,000 km
    > 65% of certified capacity within 8 year or 160,000 km
  - PHEV: > 75% of certified capacity within 5 year or 100,000 km
    > 60 % of certified capacity within 8 year or 160,000 km

  PHEV capacity reserve 15% as BEV

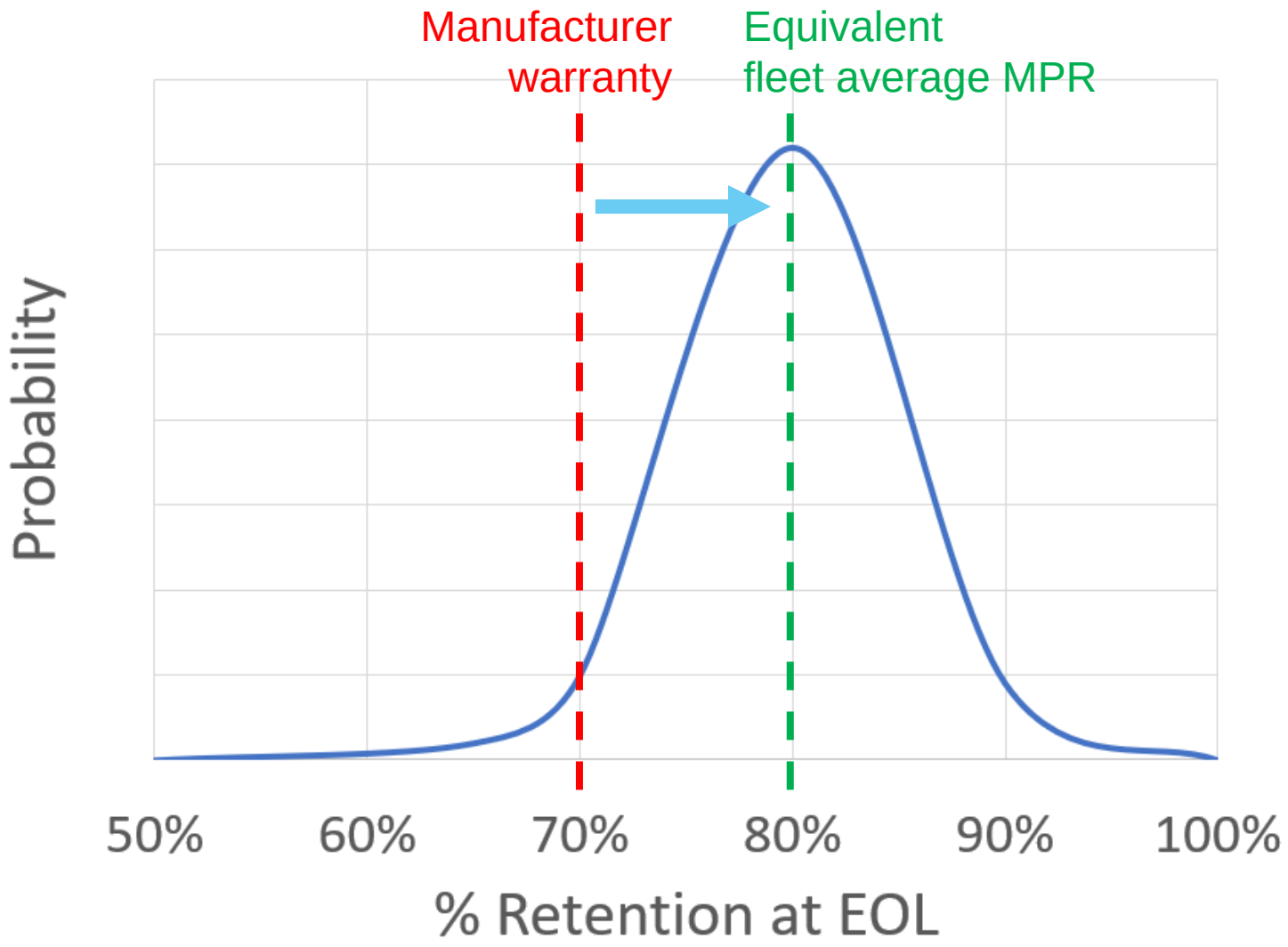
  - PHEV: > 85% of certified capacity within 5 year or 100,000 km
    > 70% of certified capacity within 8 year or 160,000 km

PEV Battery Warranties – US Market (* = Europe)

Manufacturer	Model	Warranty against failure: Years	Warranty against failure: km	Includes degradation?
Audi	e-tron	8	160,000	NO
BMW	i3	8	160,000*	70%
Chevrolet	Bolt	8	160,000	60%
Fiat	500e	8	160,000	NO
Hyundai	Ioniq, Kona	10	160,000	NO
Jaguar	i-Pace	8	160,000	70%
Kia	Niro EV	7*	150,000*	70%
Lexus	UX300e	10*	1,000,000*	70%
Mercedes	B-Class Elec drive	8	160,000	70%
Nissan	Leaf 40, 60	10	160,000	~75%
Porsche	Taycan Turbo	8	160,000	70%
Tesla	Model 3, Y	8	160-190k	70%
Tesla	Model S, X	8	240,000	70%
Volkswagen	e-Golf	8	160,000	70%

Difference between warranty and MPR

- MPR concept enforces a fleet performance
- By contrast, manufacturer warranties enforce individual performance
- For a given performance curve in the field, the warranty level chosen by OEMs is therefore lower than the “equivalent” fleet average MPR



Fleet average and individual performance

- By its nature, a fleet average MPR allows perhaps 1/2 of individual vehicles to underperform the MPR and still pass
- In this example, 50% of vehicles achieve < 80% retention (but most are > 70%)
- Shape of the curve matters
- If the distribution is sufficiently skewed, many could have << 70% retention

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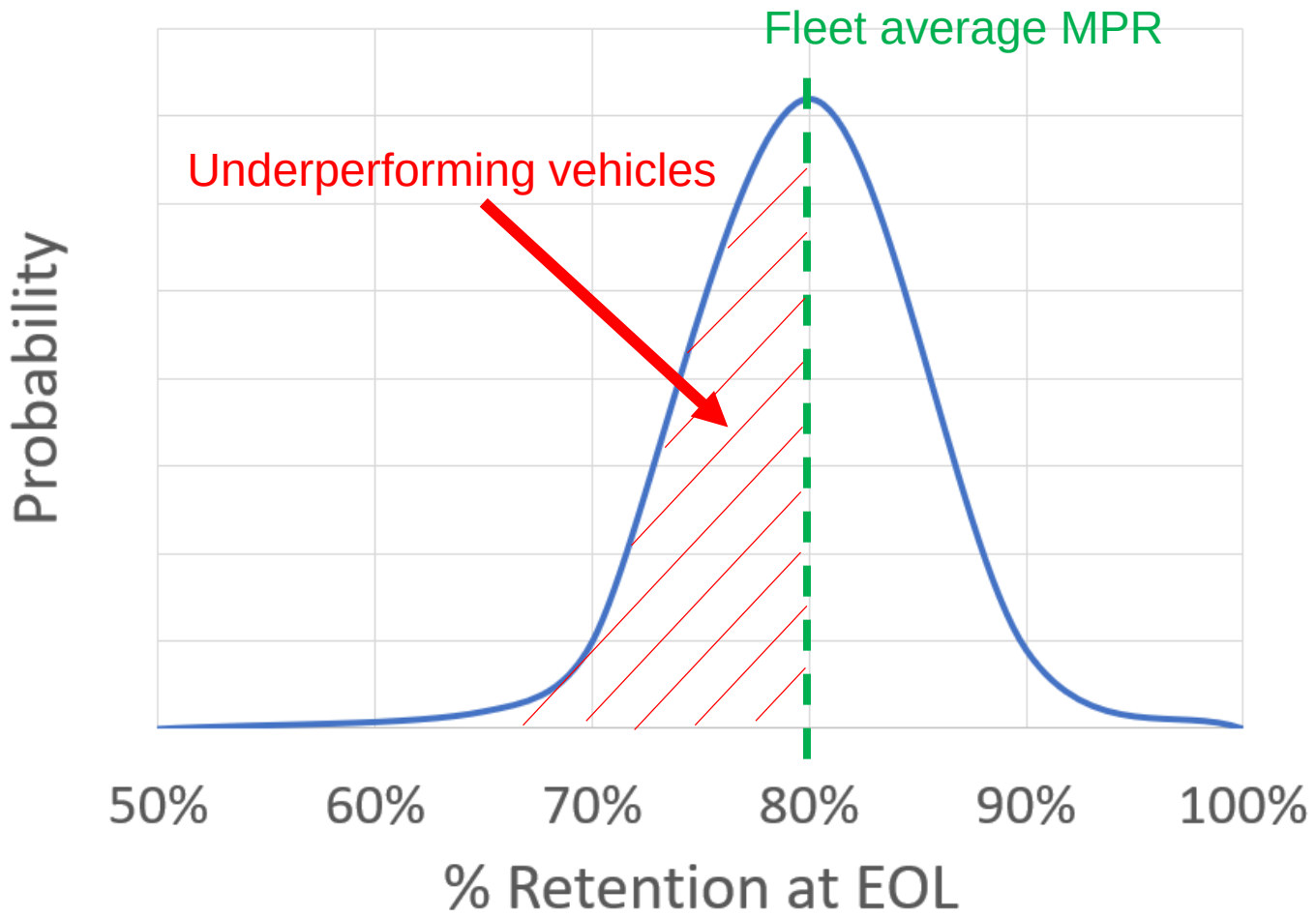
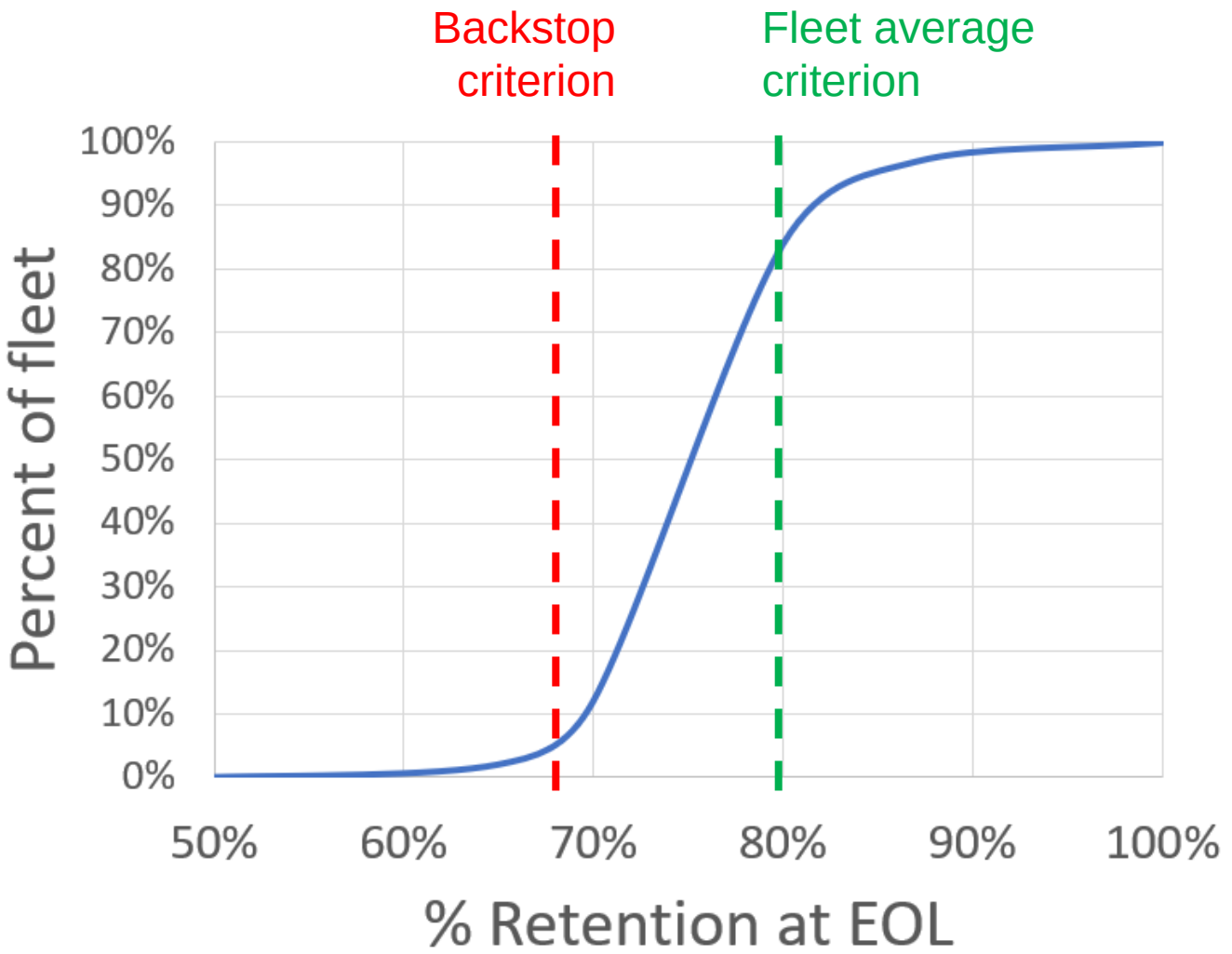
- How much individual underperformance is acceptable?
- How can we control fleet performance best?



Possible “backstop” concept for MPR structure

- MPR might consist of fleet average criterion + backstop criterion
- Or **at least the backstop criterion**
- For example:
  - Fleet must average 80% retention
  - AND not more than 5% of fleet can achieve less than 70% retention



Conclusions from data analysis

- TEMA is the best available model currently available at the EVE IWG for studying the battery performance
- TEMA has been developed from the start of the EVE IWG for this purpose
- It has been validated by the available real world measurements of battery performance/degradation
- The results of TEMA coincide with information on warranties provided by OEMs
- The proposal shown in the following is the common understanding of EC, US-EPA and ECCC

Verification

- Two families:
  - PART A: Monitor Family (assess the performance of the monitor)
  - PART B: Battery Durability Family (assess the performance of the battery)

PART A: Verification of Monitor performance

- Tolerance for phase 1 to be set at 5%, i.e. fail if measured value is less than 95% of the monitor
- Further data to be gathered in order to improve the tolerance
- Statistics can be based on sample of 3-20 vehicles statistics, based on ISO 8422:1991 and UNECE Reg. 83

Cumulative sample size (n)	Pass decision number	Fail decision number
3	0	-
4	1	-
5	1	5
6	2	6
7	2	6
8	3	7
9	4	8
10	4	8
11	5	9
12	5	9
13	6	10
14	6	11
15	7	11
16	8	12
17	8	12
18	9	13
19	9	13
20	11	12

PART B: Verification of battery durability

- BEV: > 80% of certified capacity within 5 years or 100,000 km
  > 70% of certified capacity within 8 years or 160,000 km
- PHEV: > 90% of certified capacity within 5 years or 100,000 km
  > 80% of certified capacity within 8 years or 160,000 km

- Consistent with “rock screening” because:
  - it is based on the “worst” performing vehicles currently in the market
  - similar to what manufacturers are already achieving based on the warranties
  - same criteria for all light duty vehicles (i.e. passenger cars and light commercial vehicles)

PART B: Family pass criteria

- A family shall **pass** if more than 95% of SOCC values read from the vehicle sample is above the MPRi or DPRi
- A family shall **fail** if more than 5% of SOCC values read from the vehicle sample is below the MPRi or DPRi **(i.e. backstop criterion only in phase 1)**

with

- At least 500 vehicles from the same family shall be “read”
- If there are less than 500 vehicles available then the vehicle survey shall be used to exclude vehicles that have been “abnormally used”

Further developments for Phase 2

- Further work is needed in order to define criteria based on Range
- Range deterioration shall only be monitored during Phase 1
- Data need to be collected for improving the tolerance on the monitor decision criteria
- Data need to be collected for possibly strengthening the criteria on capacity (and possibly adding average performance)

- *CPs will need to set up appropriate schemes for monitoring range and capacity to inform Phase 2*

Proposal for new Battery Regulation in EU

- Published on 10 December 2020
- Text available in:
- https://ec.europa.eu/commission/presscorner/detail/en/ip_20_2312
- Recognises that performance criteria for in-vehicle batteries will be set by the UNECE EVE IWG.
- Avoids double regulation on this issue in the EU
- Need to stick to initial time planning

Advantages of this proposal

- It provides some immediate solutions for proceeding quickly with the GTR
- Taking into account proposals made by Japan
- Acknowledges that currently there is little information on which to base a decision on Range
- Is consistent with warranties of cars today in the market
- Provisions can be made for new technologies in local Regulations
- Allows time for monitoring and improving methodology

Thank you for the attention

European Commission

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. (2013);		
		Sarasketa-Zabala et Al. (2015);		
NCM + spinel Mn	Wang et Al. (2014);		-	Wang et Al. (2014);
NCM – LMO	-	Cordoba-Arenas et Al. (2014);	-	Cordoba-Arenas et Al. (2015);

Calendar + Cycle (4 Combinations):

#1 (LiFePO4): Sarasketa-Zabala et Al. (2013/14) model for calendar plus Wang et Al. (2011) model for cycle;

#2 (LiFePO4): 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)

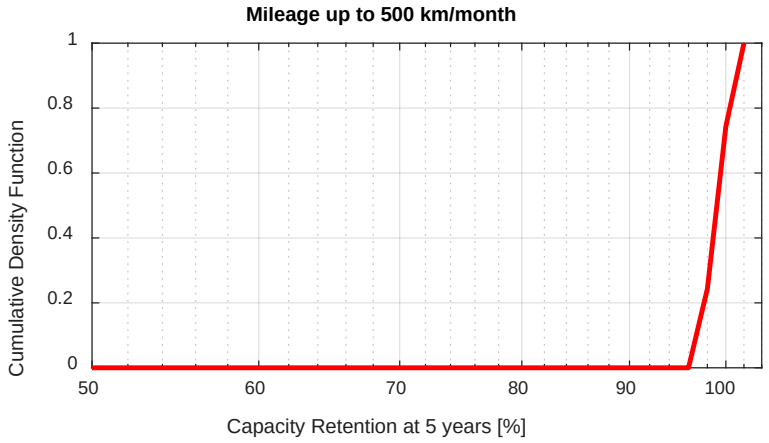
Vehicle Electric Architectures (examples)

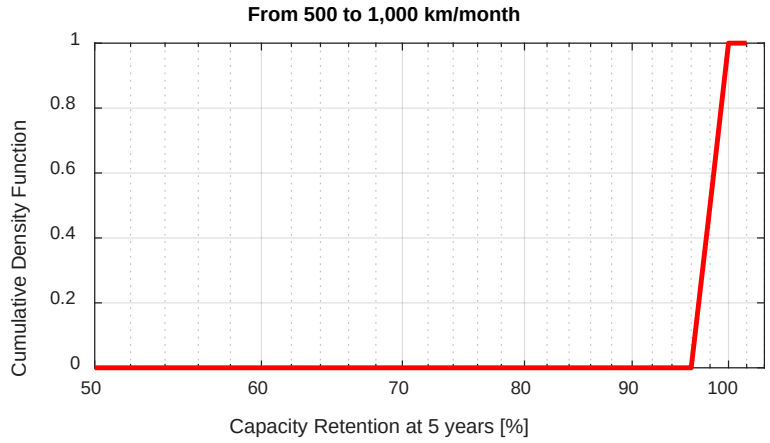
PHEV 1 **PHEV 2** **PHEV 3** **BEV 1** **BEV 2** **BEV 3** **BEV 4**

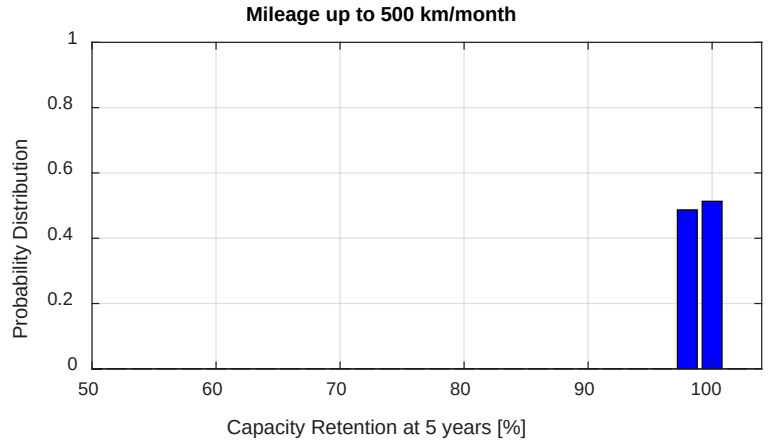
	Vehicle Type	Battery Size [Wh]	Battery Shape	No. of Cells [#] and Type	Reference Voltage [V]	Electric Architecture	Usable Energy at BoL [Wh]	Usable Energy at EoL [Wh]	Reserve [% of battery capacity]	Energy consumption [Wh/km]
HP PHEV	PHEV 1	16,000	T-shaped	192 – pouch	365	2P-96S	12,000	9,600	25%	205
Mid-sized PHEV	PHEV 2	8,800	Parallelepiped	95-Prismatic	351	95S	6,600	5,280	25%	160
Mid-sized PHEV	PHEV 3	12,000	Parallelepiped	80-Prismatic	300	80S	9,000	7,200	25%	194
Mid-sized BEV	BEV 1	24,000	Parallelepiped	192 – pouch	360	48S-2P-2S	18,000	14,400	15%	210
HP large-sized BEV	BEV 2	85,000	Flat	6,912 - cylindrical	345	16S-72P-6S	63,750	51,000	15%	235
HP large-sized BEV	BEV 3	75,000	Flat	4,416 - cylindrical	345	4S-46P-23|25S	56,250	45,000	15%	180
HP large-sized BEV	BEV 4	95,000	Flat	432 – pouch	396	4P-108S	71,250	57,000	15%	262

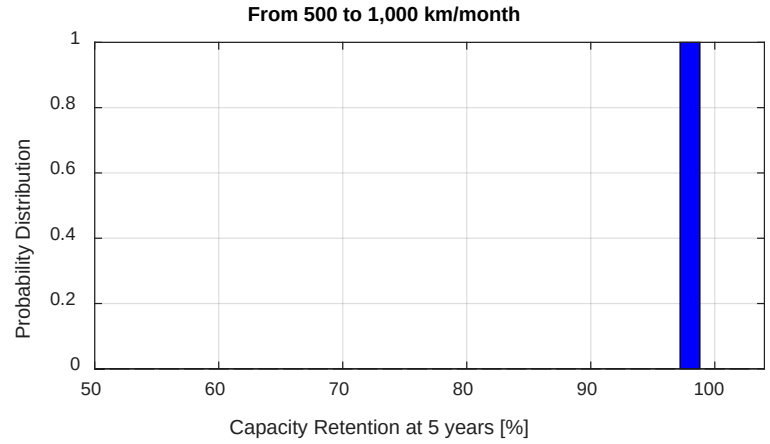
Capacity retention– PHEV- 1

Capacity retention at 5 years– PHEV -1 – Str.1









>95%

EoL 20% @ 14.9yrs

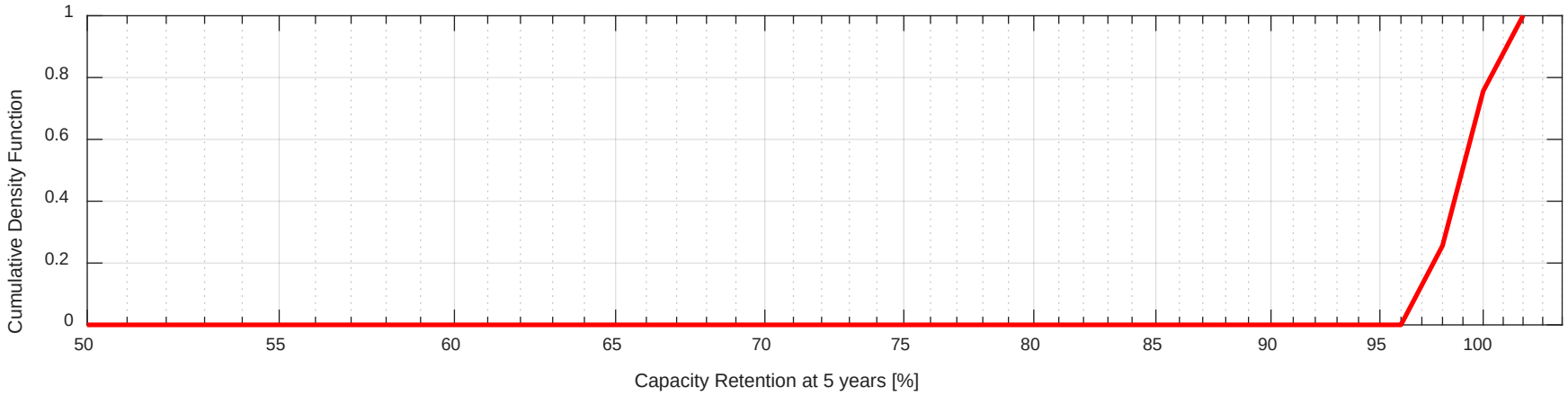
EoL 20% @ 11.6yrs

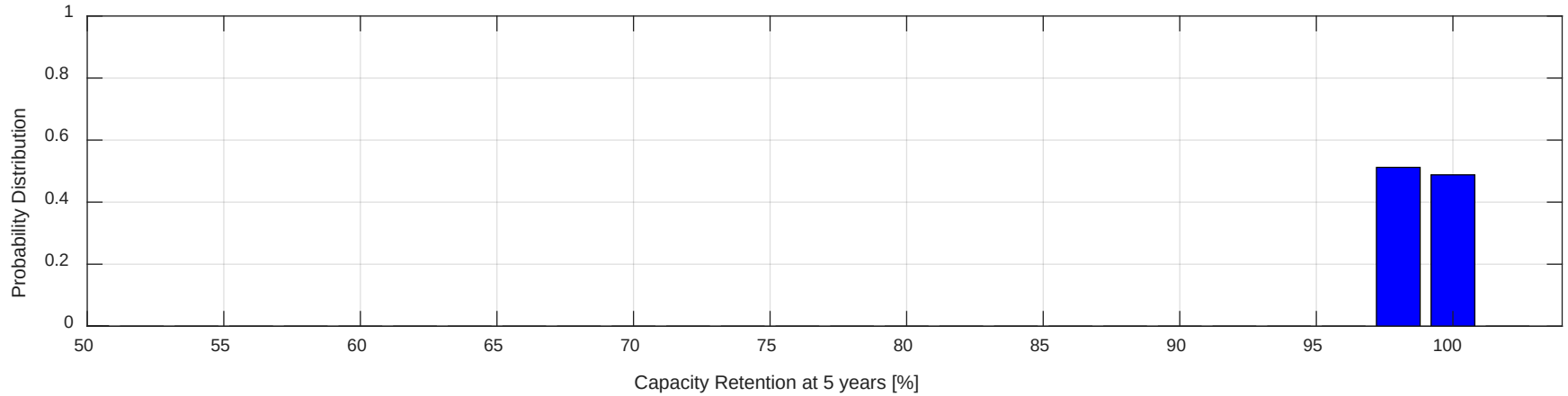
Li-Ion NCM-LMO (2015) - Modena province area

European Commission

Capacity retention at 5 years– PHEV -1 – Str.1

All km/month bins distributions





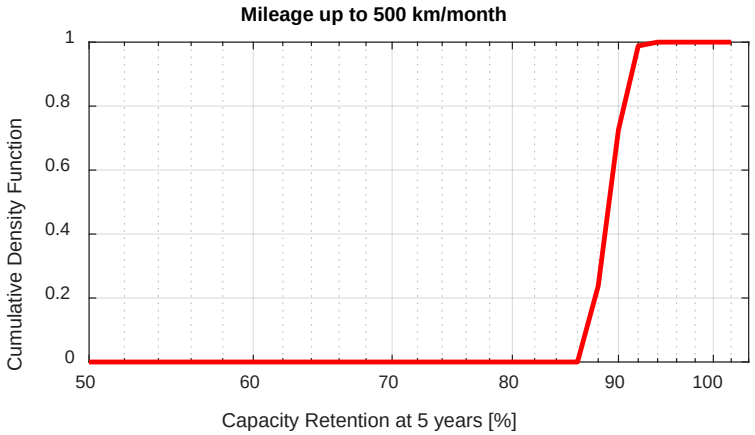
>95%

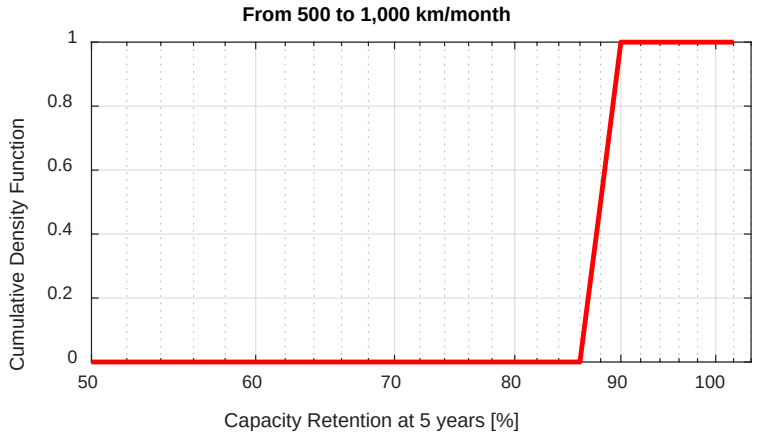
Li-Ion NCM-LMO (2015) - Modena province area

European Commission

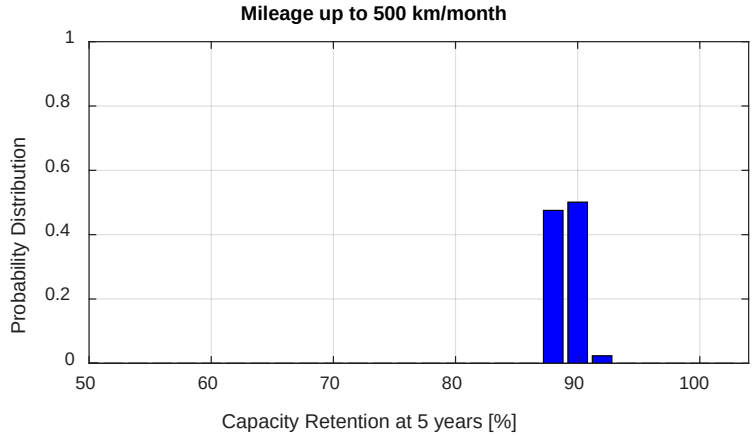
Capacity retention at 5 years– PHEV -1 – Str.1

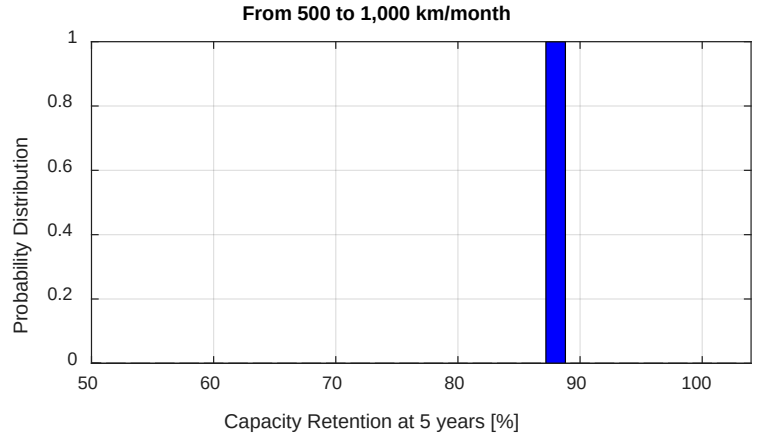
Capacity reserve 15%





>85%





EoL 20% @ 10.0yrs

EoL 20% @ 8.8yrs

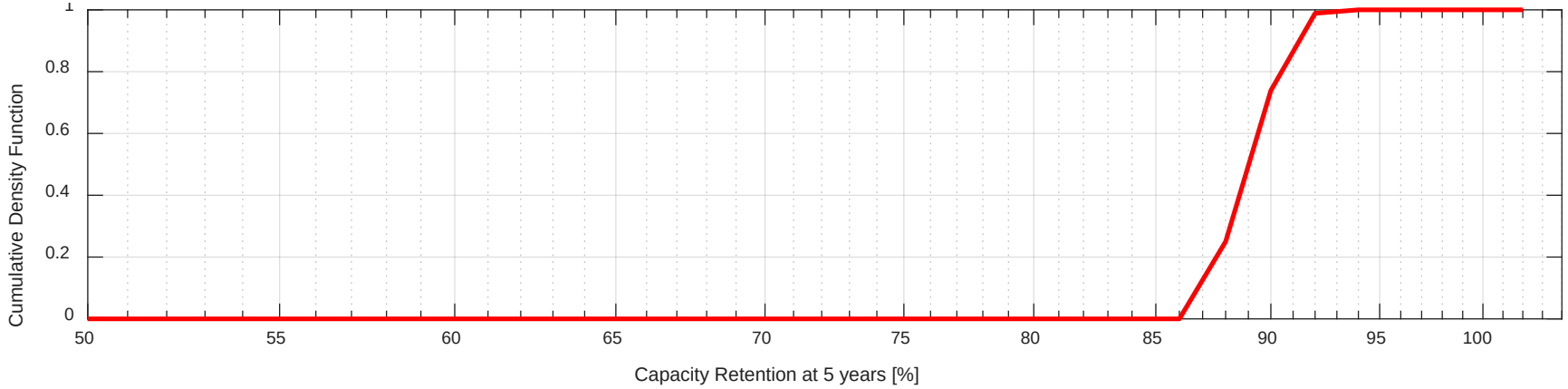
Li-Ion NCM-LMO (2015) - Modena province area

European Commission

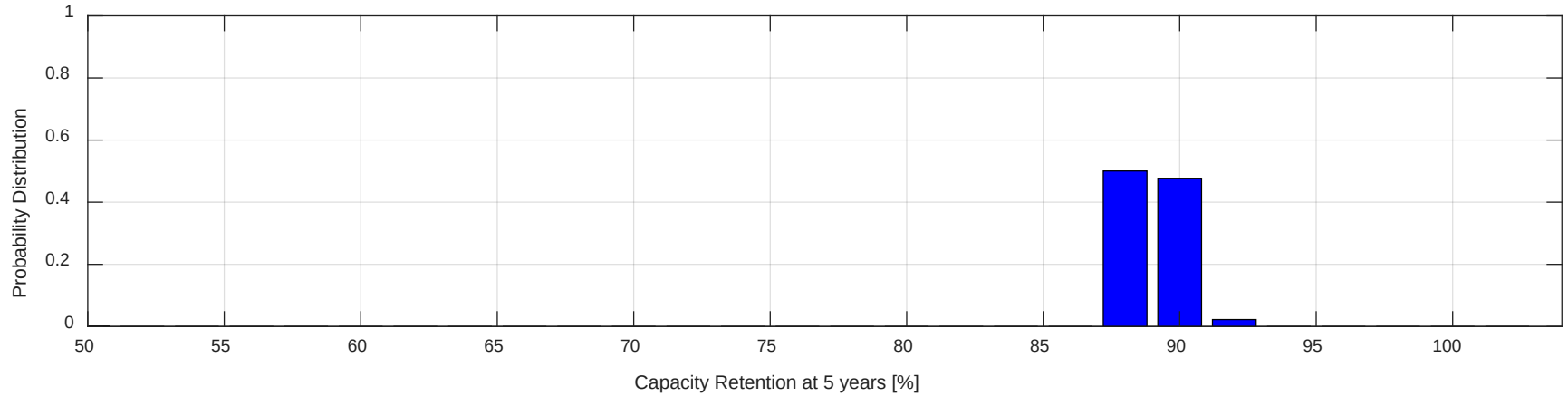
Capacity retention at 5 years– PHEV -1 – Str.1

All km/month bins distributions

Capacity reserve 15%



>85%



Li-Ion NCM-LMO (2015) - Modena province area

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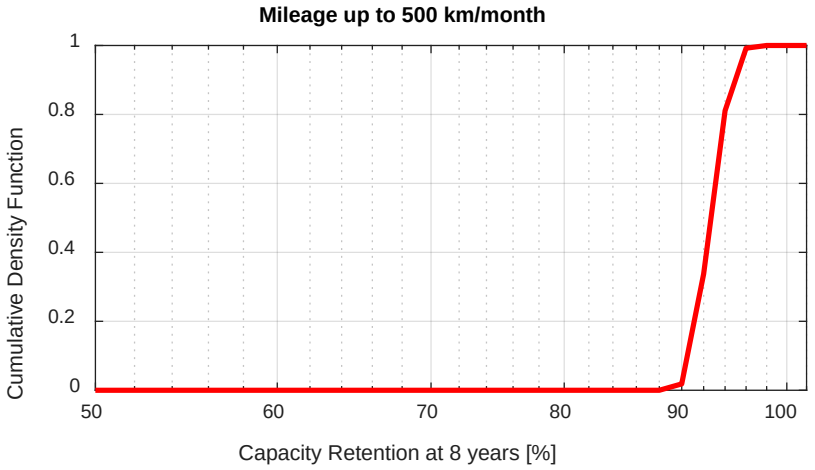
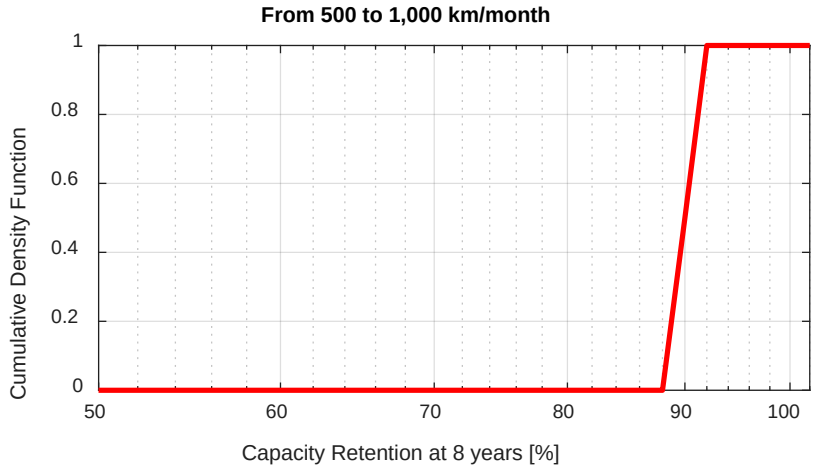
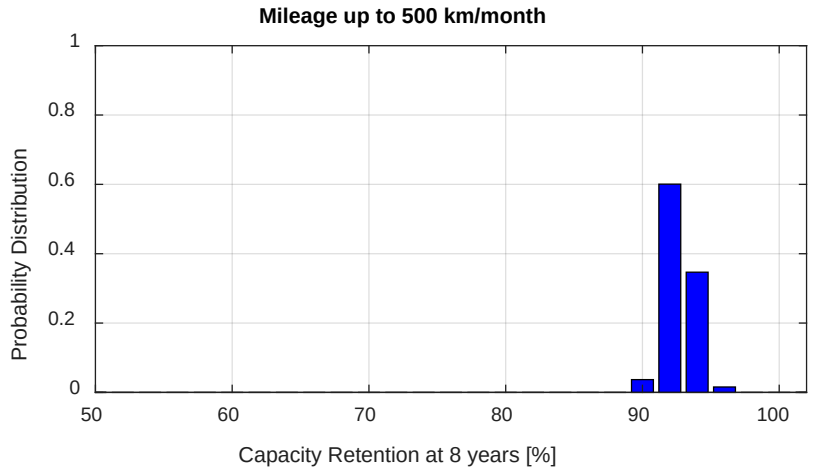
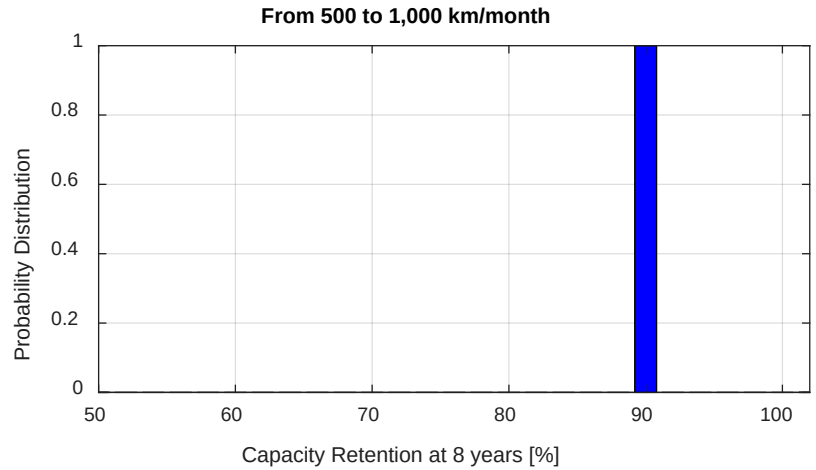
Capacity retention at 8 years– PHEV -1 – Str.1





>90%





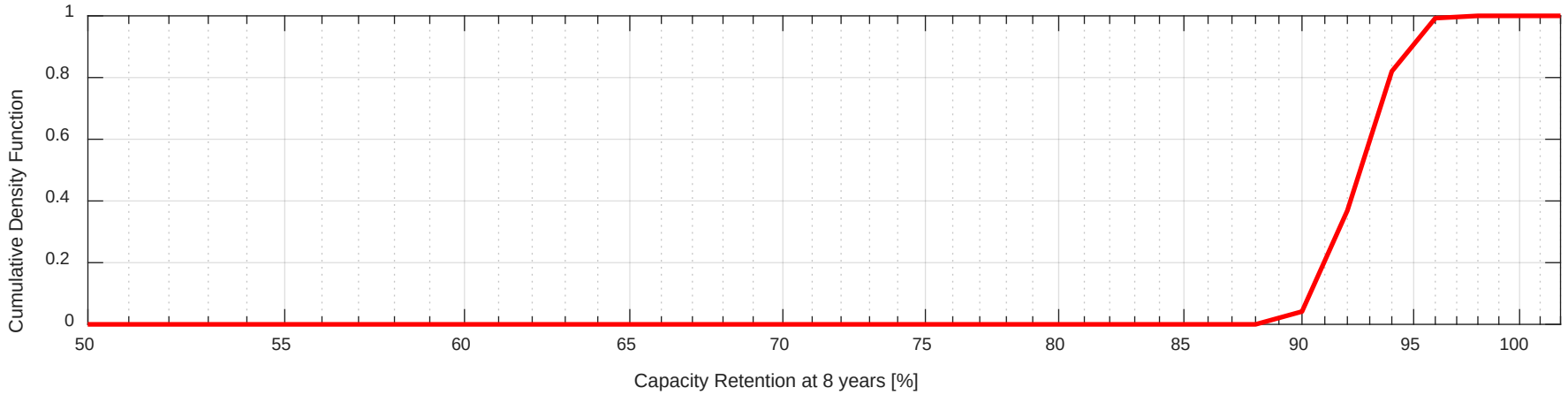
EoL 20% @ 14.9yrs

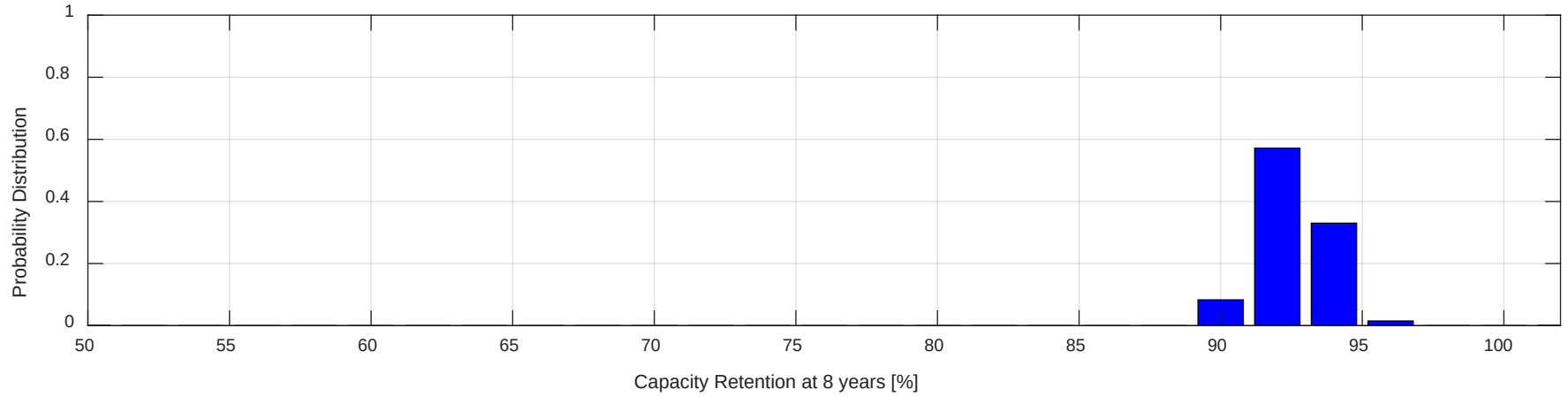
EoL 20% @ 11.6yrs

Li-Ion NCM-LMO (2015) - Modena province area

Capacity retention at 8 years– PHEV -1 – Str.1

All km/month bins distributions





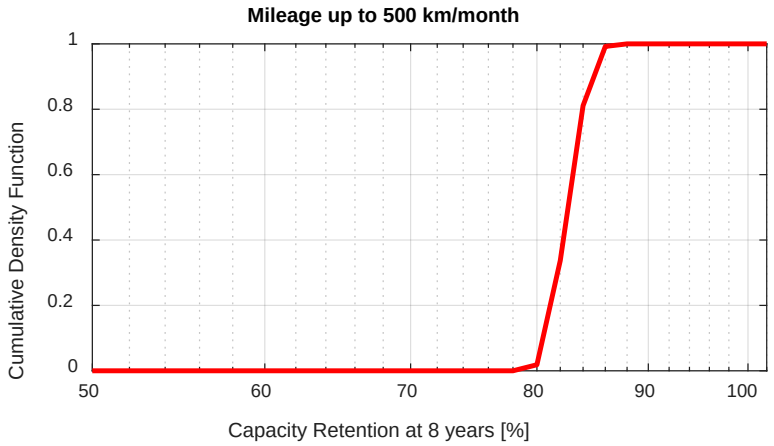
>90%

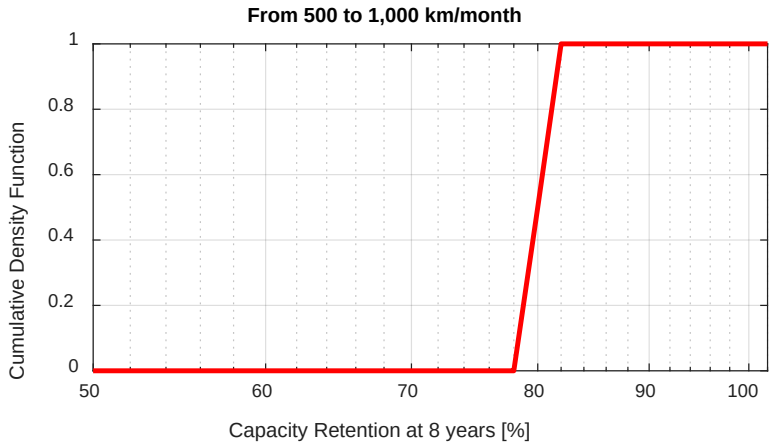
Li-Ion NCM-LMO (2015) - Modena province area

European Commission

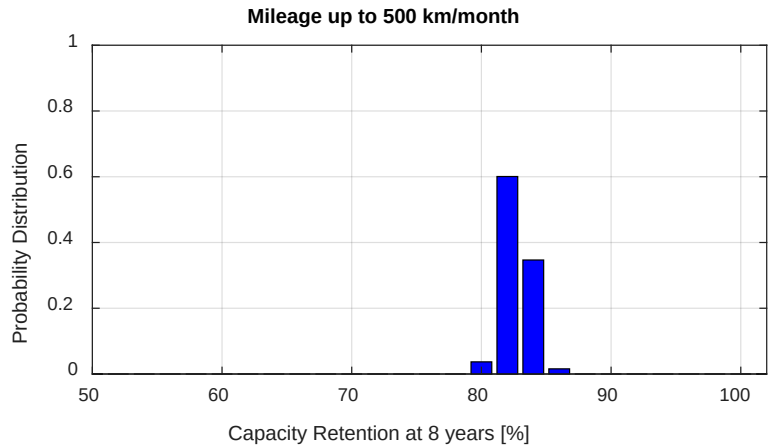
Capacity retention at 8 years– PHEV -1 – Str.1

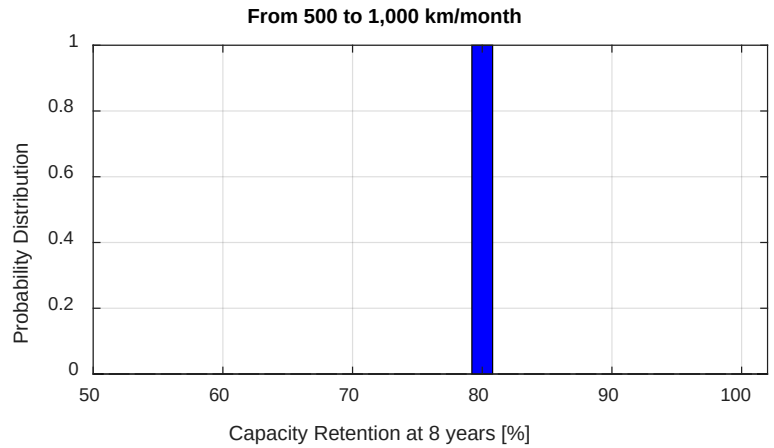
Capacity reserve 15%





>70%





EoL 20% @ 10.0yrs

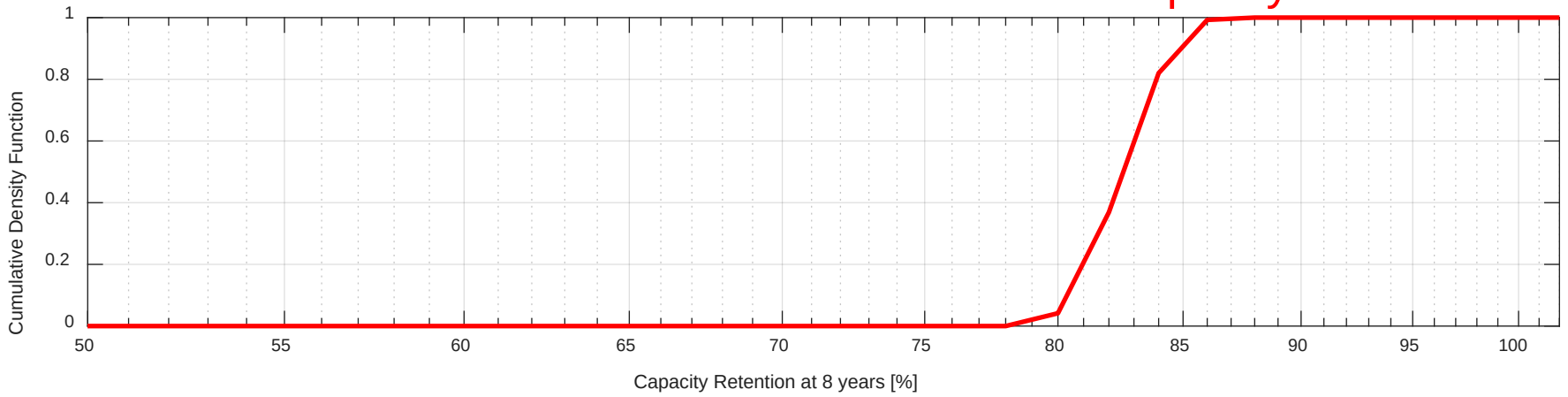
EoL 20% @ 8.8yrs

Li-Ion NCM-LMO (2015) - Modena province area

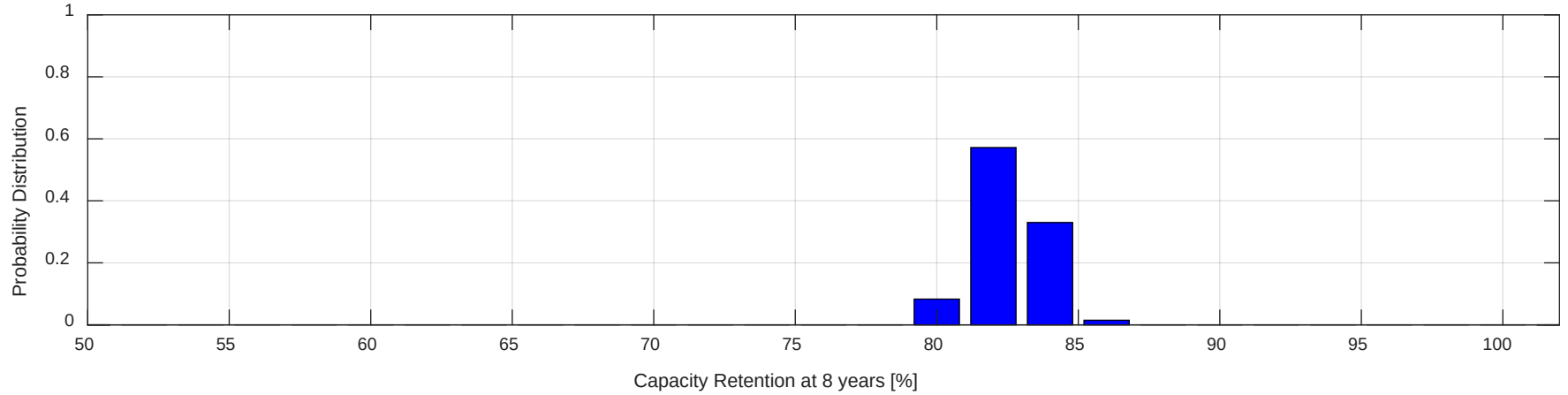
Capacity retention at 8 years– PHEV -1 – Str.1

All km/month bins distributions

Capacity reserve 15%



>70%



Li-Ion NCM-LMO (2015) - Modena province area

European Commission

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. (2013);		
		Sarasketa-Zabala et Al. (2015);		
NCM + Spinel Mn	Wang et Al. (2014);		-	-
NCM – LMO	-	Cordoba-Arenas et Al. (2014);	-	Cordoba-Arenas et Al. (2015);

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.:

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

- 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;