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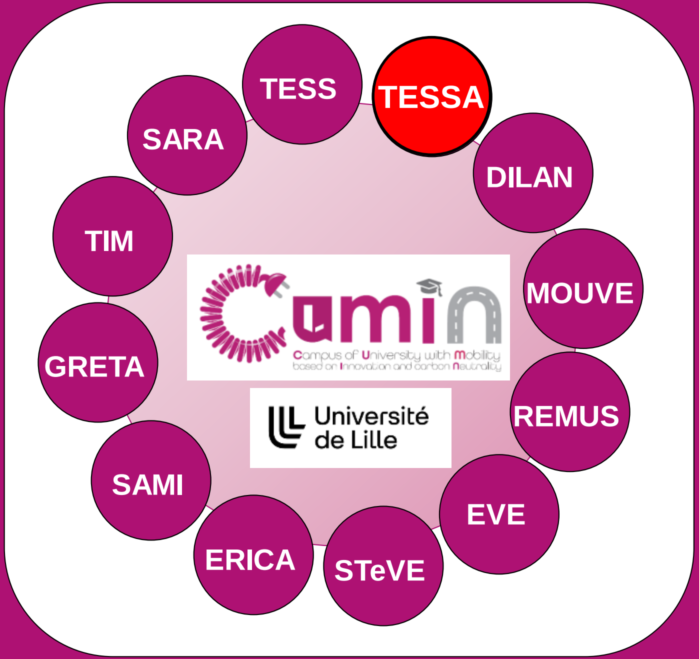

CUMIN - TESSA

Techno-Economic Impacts of EV Battery Replacements

Martin Chaud[1], Ronan German[1], Eric Hittinger[2], Alain Bouscayrol[1], Elodie Castex[3]

[1] L2EP, Lille, France
[2] RIT, Rochester, USA
[3] TVES, Lille, France

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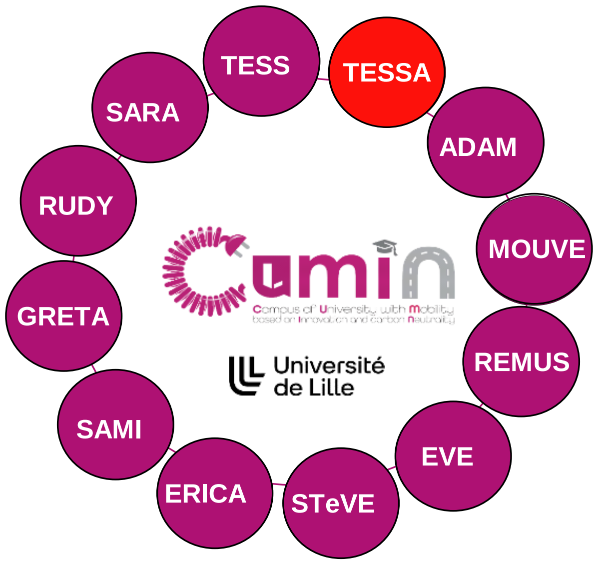
Context and Objective

Context and objective

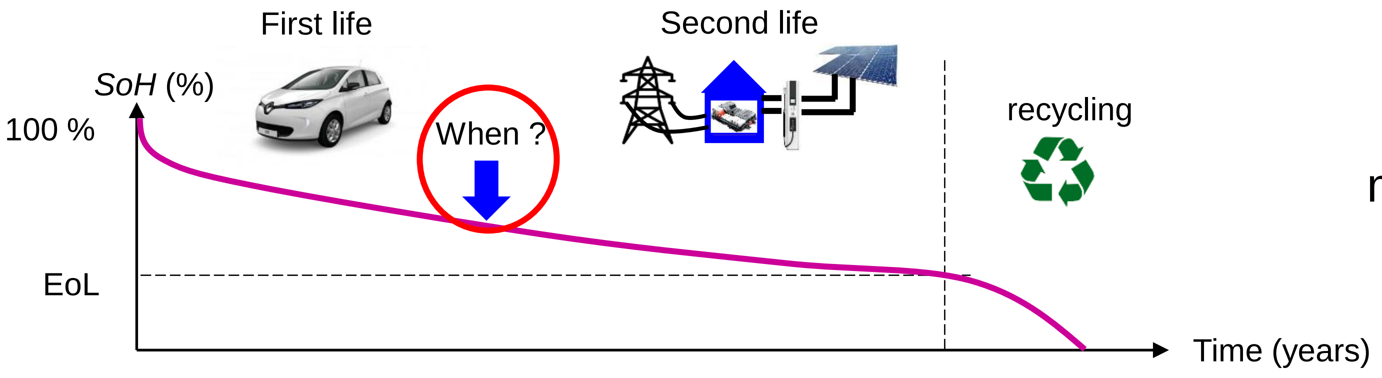


TESSA: Techno-Economic Study of Second life EV batteries for Affordable e-mobility campus

Objective: Study the interest of second life batteries in a multi-domain framework

Technical domain

How to predict battery aging?



Economic domain

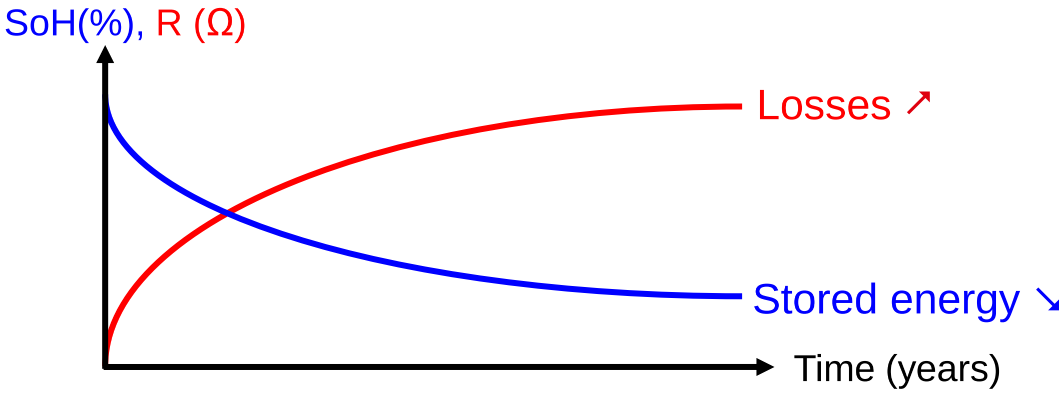
When is the best moment to switch to second life ?

Study the techno-economic interest of battery change

EV battery techno-economic model development

Batteries undergo performances degradation over time → Aging

Battery aging



Degradation depends on the usage

→ Impact on the battery value

Development of a multi-domain model

Technical model

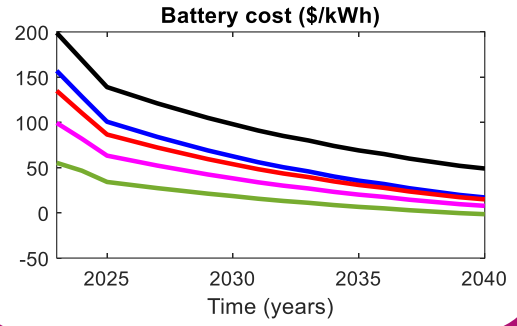
Usage

Vehicle application

Battery

Multi-domain modelling

Economic model



→ **Battery price**

→ Study of techno-economic impact of replacement time for EV batteries

Outline

1. Battery technical modeling
2. Techno-economic modeling
3. Case studied and results

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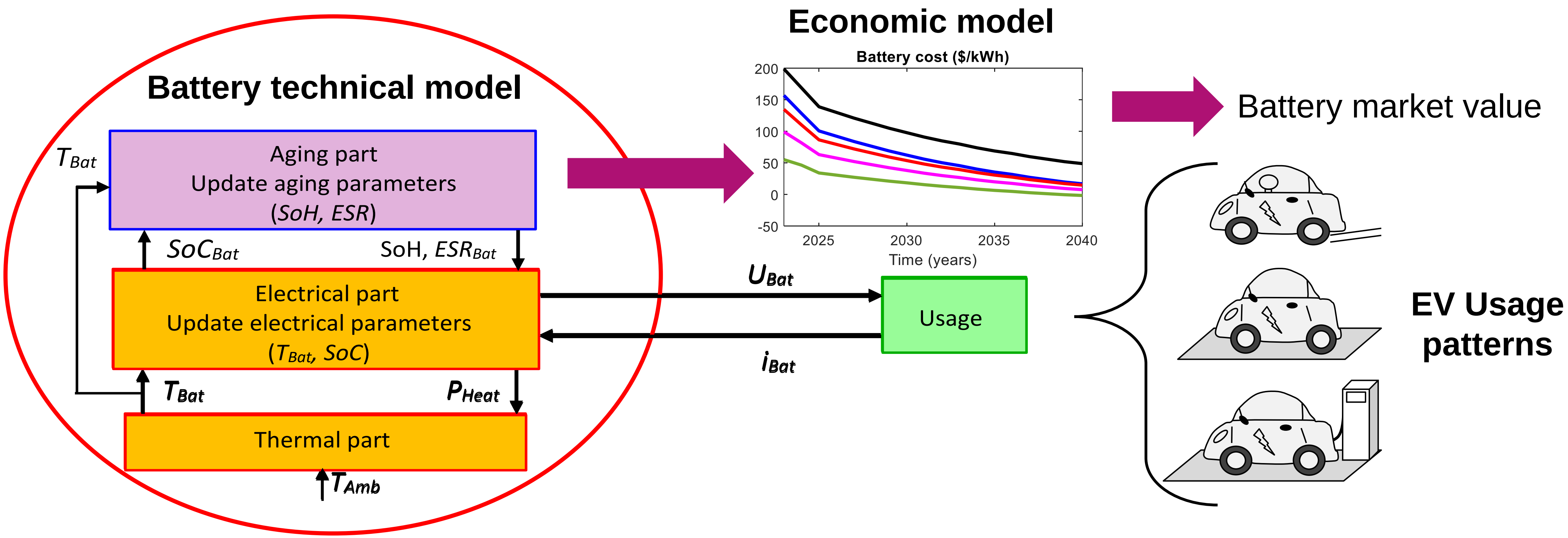
Battery technical modeling

L2EP Laboratoire d'électrotechnique et d'électronique de puissance de Lille
TVES Territoires Villes Environnement & Société EA 4477
LaMcube Laboratoire de mécanique, multiphysique, multiéchelle
CLERSÉ
LILLE
Gériico
MEL MÉTROPOLE EUROPÉENNE DE LILLE

The battery model is composed of several parts

Multi-domain modeling in interaction with the EV usage



Complex multi-domain simulation with many interactions: Need a unified representation

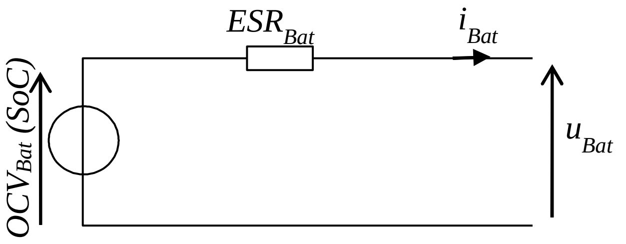
Energetic Macroscopic Representation **(EMR)**: based on power exchange → Adapted for multi-domains simulations

[Bouscayrol 2012]

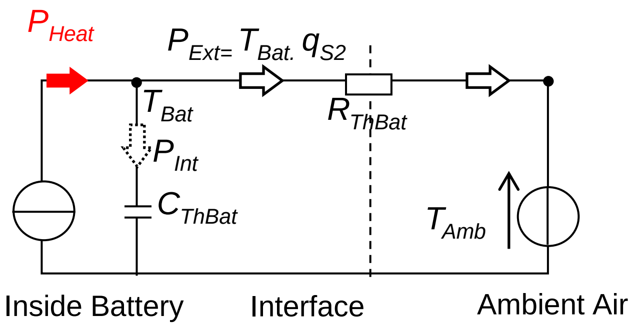
Electro-thermal modelling of batteries [German 2020]

Model

Electrical part

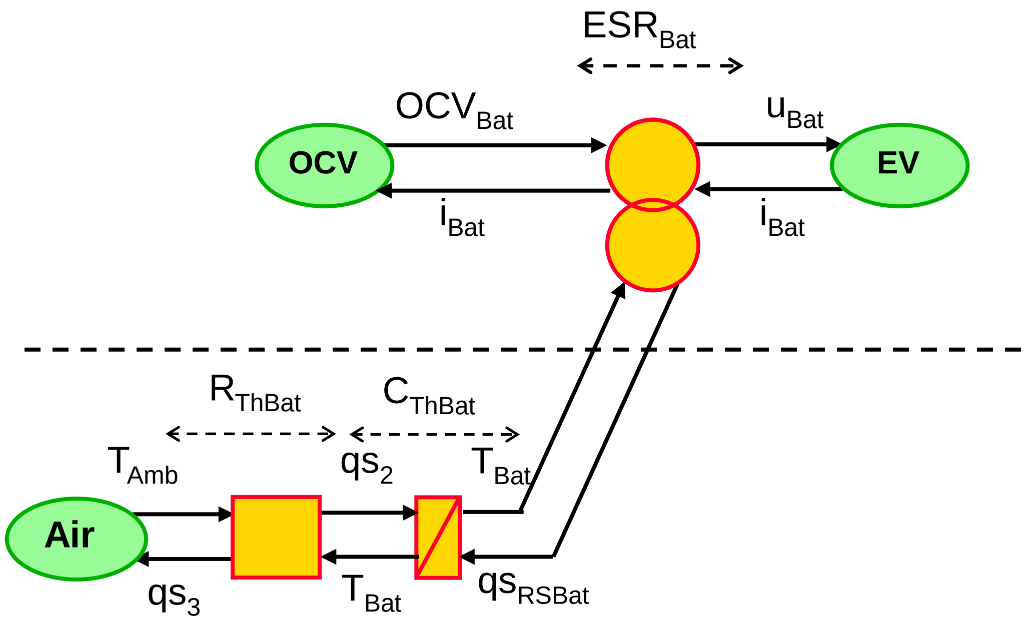


Thermal part



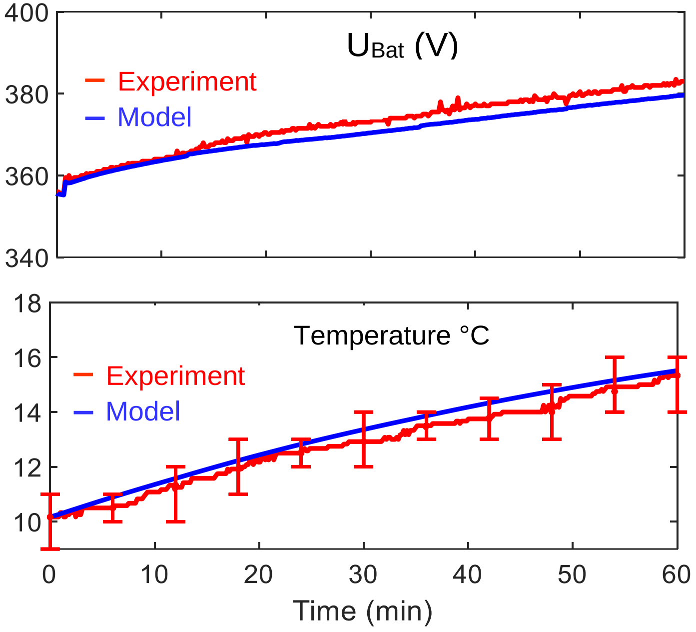
$$P_{Heat} = ESR_{Bat} i_{Bat}^{2}$$

Organization : EMR



ESR_{Bat} is the electro/thermal interface

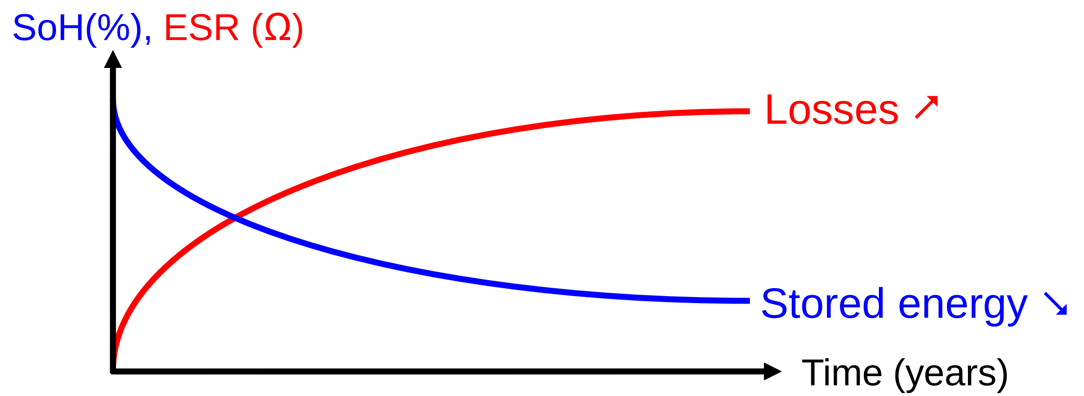
Model validation



Renault Zoe recharge

Battery aging model

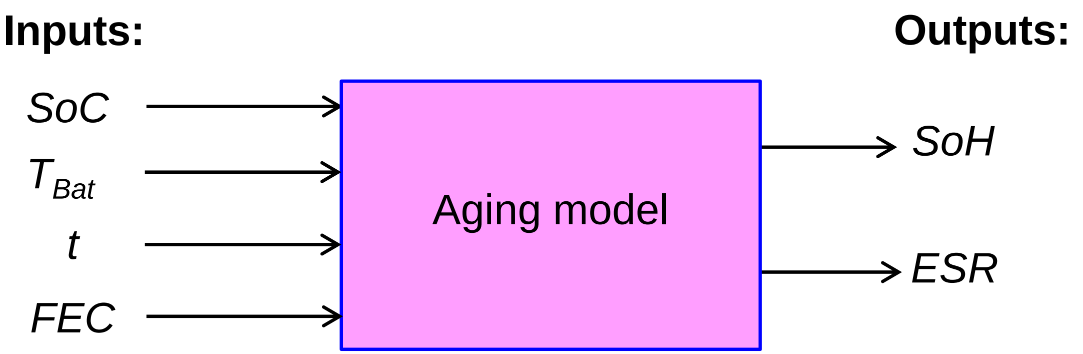
Battery aging



For the capacity [Ndiaye 2024]

Inputs: SoC, temperature T_{Bat}, time t, Number of cycle FEC

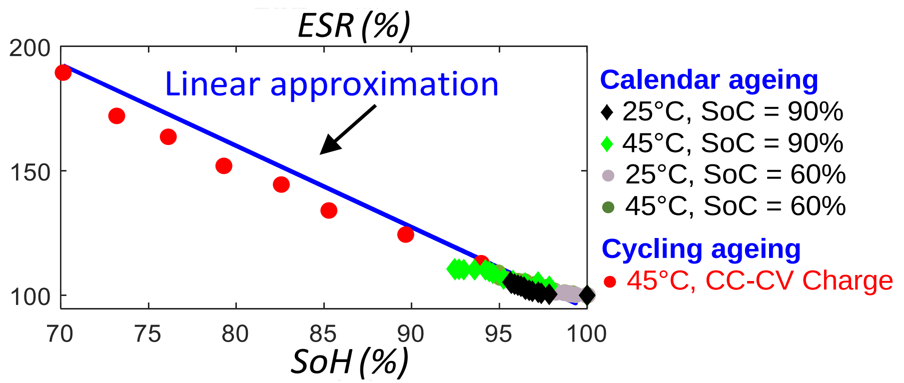
Output: Capacity C



For the resistance

Linear approximation of ESR_{bat}(SoH)
Experimental data from **[LG Chem 2018]**

Input : State of Health SoH   Output: Resistance ESR



Developed and validated for the Renault Zoe

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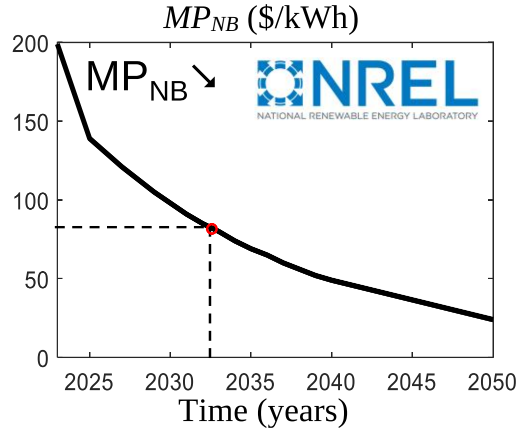
Techno-economic modeling

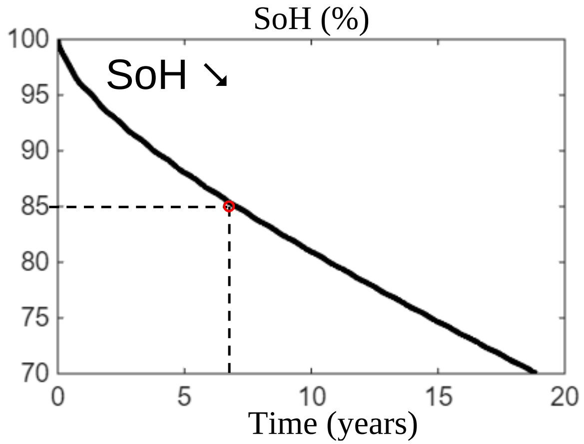
Simplified economic modelling based on technical inputs

Updated value of batteries depends of many parameters

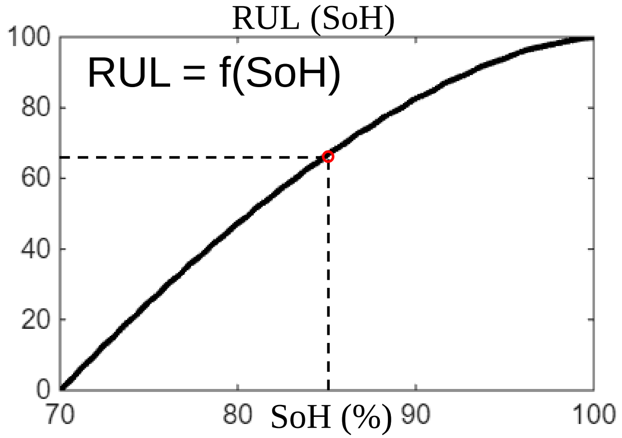
New Battery price



State of Health SoH



Remaining useful Life RUL



EMR representation (estimator)

Market price of the battery in use

$$MP_{Bat}(t) = MP_{NB}(t)\, SoH(t)\, RUL(t)$$

Battery Cost of Ownership

$$BCO = MP_{NB}(0) + \left(\sum_{1}^{n} MP_{NB}(t) - MP_{Bat}(t)\right) - MP_{Bat}(EoL)$$

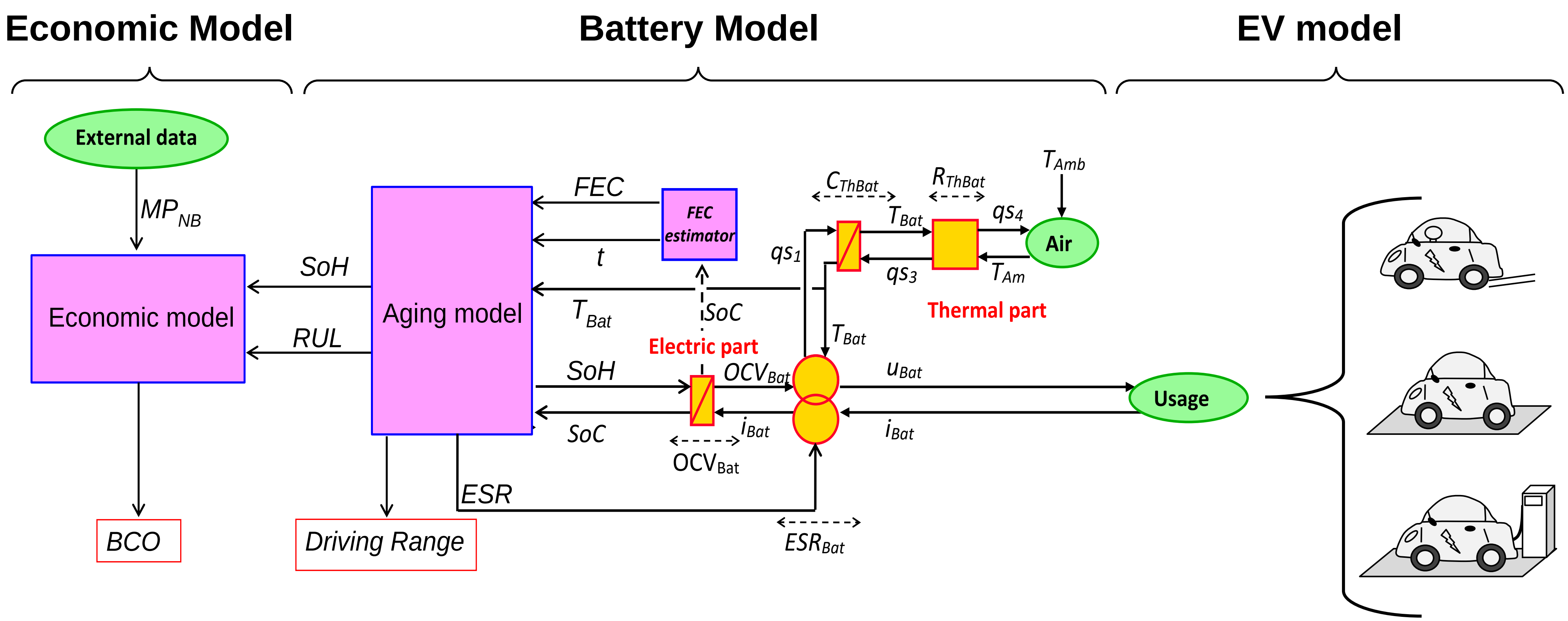
Initial battery price

Battery cost of replacement

Final battery resale price

The economic model takes technical parameters as an input

Energetic Macroscopic Representation of the global model



Obtention of battery cost of ownership and driving range with the EV usage

Study of impact of replacements with the EV usage

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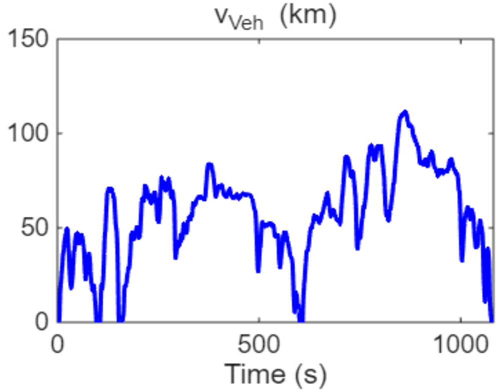
Case studied and results

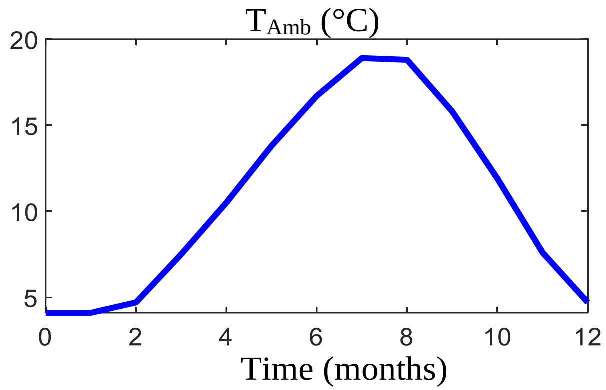
Usage pattern and results

Medium usage (34.6km/day)

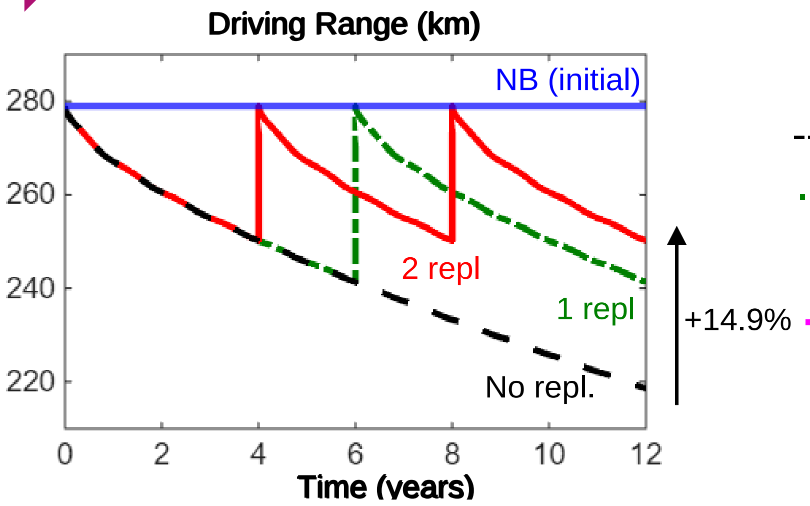


-Artemis Extra Urban cycle
-1 charge every 3 days

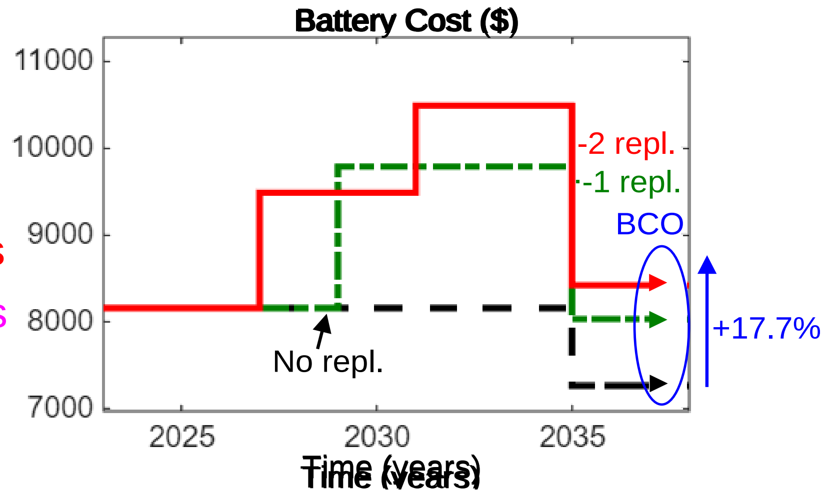
Input: Average ambient temperature Lille, France



Simulation of the global model until End of Life (SoH=70%)



-- No replacements
-· Replacement at 6 year
- Replacements every 4 years
·· Replacements every 3 years



14.9% increase between 0 and 3 replacements

17.7% Difference between 0 and 3 replacements

Frequent replacements → Recovery of ~15% of the driving range for a moderate increase in cost

Conclusion

- Connection of economic and technical model
- Study of the impact of battery replacements from the user perspective
- Replacing the battery leads to an increase in driving range at a moderate increase in cost

Perspectives

- Integrate ecological aspects and recycling of batteries
- Develop interactions between economic and technical models
- Implement second-life usage in the global study

Acknowledgment

WILL (Welcoming Internationals to LiLLe) programme

Bénéficie du soutien financier de la Région Hauts-de-France

Ce travail a bénéficié d'une aide de l'Etat gérée par l'Agence Nationale de la Recherche au titre du 3eme PIA, intégré à France 2030 portant la reference « ANR-21-IDES-0006»

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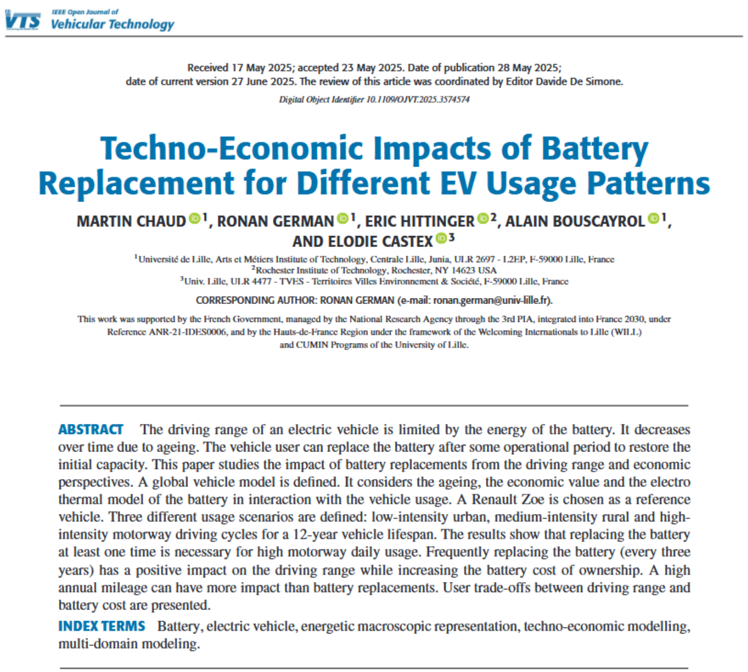

IEEE Open Journal of Vehicular Technology

Received 17 May 2025; accepted 23 May 2025. Date of publication 28 May 2025; date of current version 27 June 2025. The review of this article was coordinated by Editor Davide De Simone.

Digital Object Identifier 10.1109/OJVT.2025.3574574

Techno-Economic Impacts of Battery Replacement for Different EV Usage Patterns

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This work was supported by the French Government, managed by the National Research Agency through the 3rd PIA, integrated into France 2030, under Reference ANR-21-IDES0006, and by the Hauts-de-France Region under the framework of the Welcoming Internationals to Lille (WILL) and CUMIN Programs of the University of Lille.

ABSTRACT The driving range of an electric vehicle is limited by the energy of the battery. It decreases over time due to ageing. The vehicle user can replace the battery after some operational period to restore the initial capacity. This paper studies the impact of battery replacements from the driving range and economic perspectives. A global vehicle model is defined. It considers the ageing, the economic value and the electro thermal model of the battery in interaction with the vehicle usage. A Renault Zoe is chosen as a reference vehicle. Three different usage scenarios are defined: low-intensity urban, medium-intensity rural and high-intensity motorway driving cycles for a 12-year vehicle lifespan. The results show that replacing the battery at least one time is necessary for high motorway daily usage. Frequently replacing the battery (every three years) has a positive impact on the driving range while increasing the battery cost of ownership. A high annual mileage can have more impact than battery replacements. User trade-offs between driving range and battery cost are presented.

INDEX TERMS Battery, electric vehicle, energetic macroscopic representation, techno-economic modelling, multi-domain modeling.

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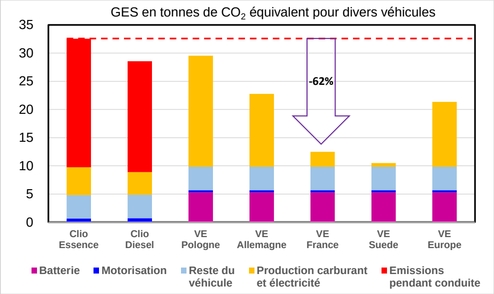

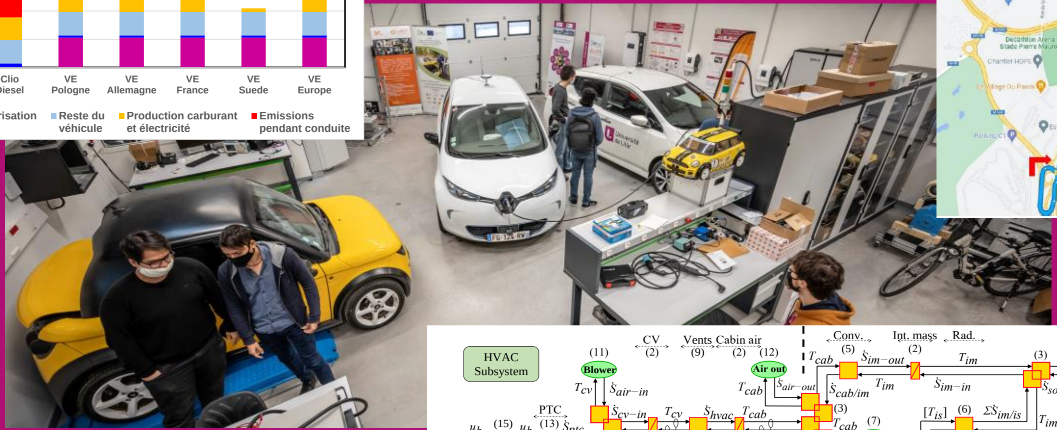

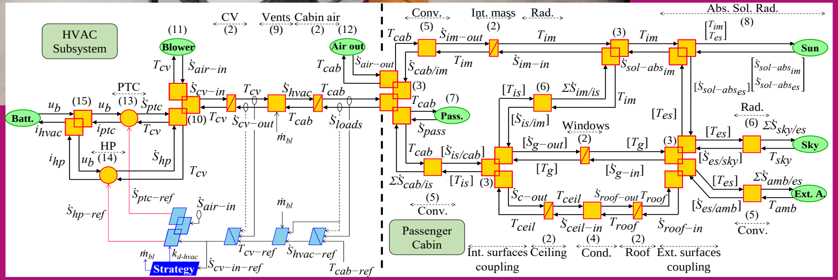

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Appendix : Battery aging model

Need a model that can be implemented into a system simulation

For the capacity [Ndiaye 2024]

Inputs: SoC, temperature T_{Bat}, time t, Number of cycle FEC

Output: dC_{loss}

SoC : Linear → $(A + BSoC)$

T_{Bat} : Arrhenius law → $e^{\frac{-Ea}{k_B T_{Bat}}}$

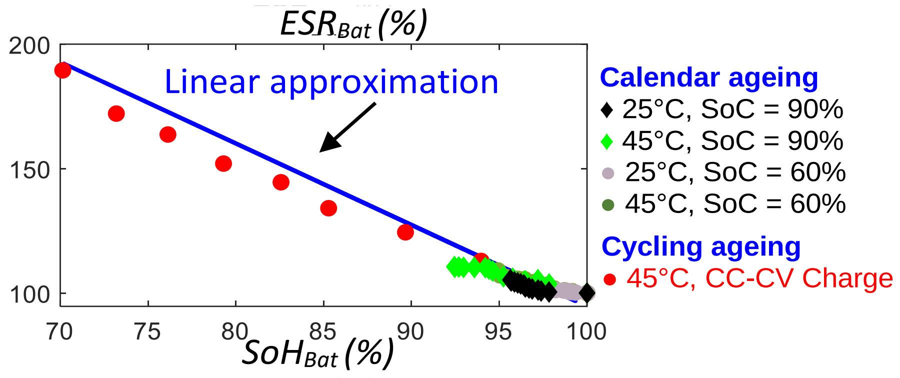
t : Exponent → t^z

FEC : Exponent → $k_{FEC} FEC^{\alpha}$

$$dC_{loss_{t \to t+dt}} = d\left[(A + BSoC)e^{\frac{-Ea}{k_B T_{Bat}}} t^z + k_{FEC} FEC^{\alpha}\right]$$

For the resistance

Linear approximation of $ESR_{bat}(SoH)$
Experimental data from **[LG Chem 2018]**

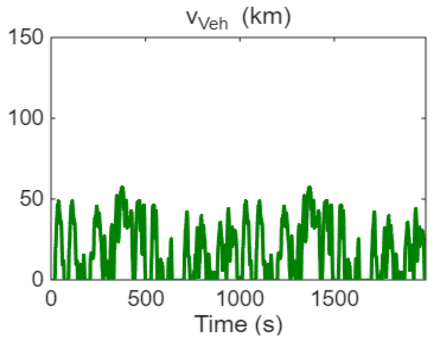


$R^2 = 0.96$, RMSE = 4.4%

Developed and validated for the Renault Zoe

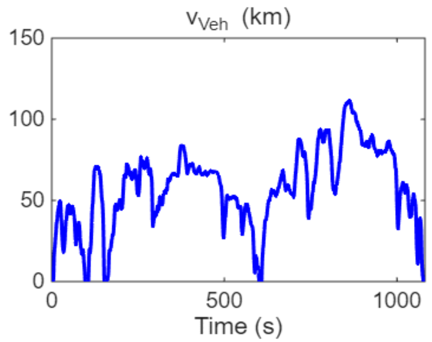
Appendix : 3 Different usage patterns are considered

Low usage (20km/day)



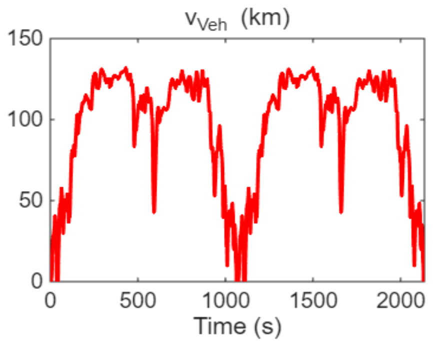
-Urban cycle
-1 charge every 3 days

Medium usage (34.6km/day)

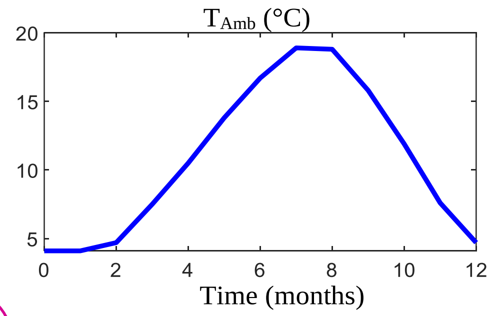


-Extra Urban cycle
-1 charge every 3 days

High usage (115km/day)



-Motorway cycle
-1 charge every day



Input: Average ambient temperature Lille, France

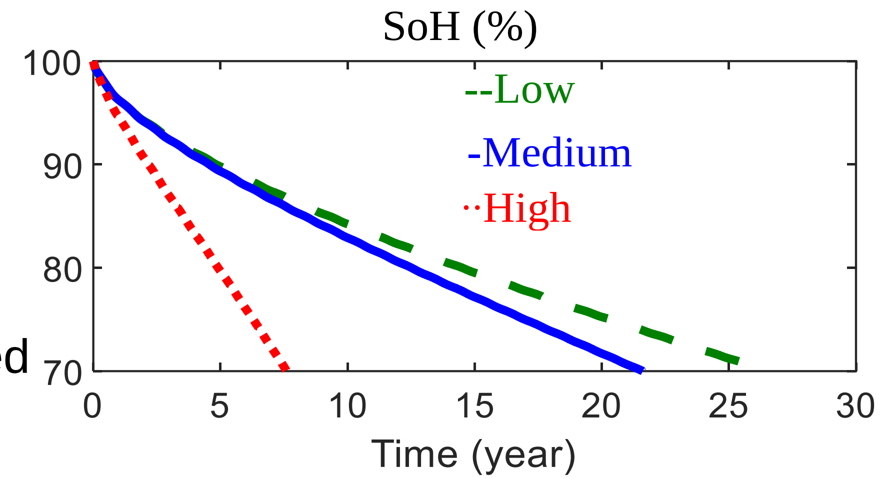
➡ Simulation of the global model until End of Life (SoH=70%)

Results for SoH and RuL

System simulated for each usage pattern until SoH reaches 70% (EoL)

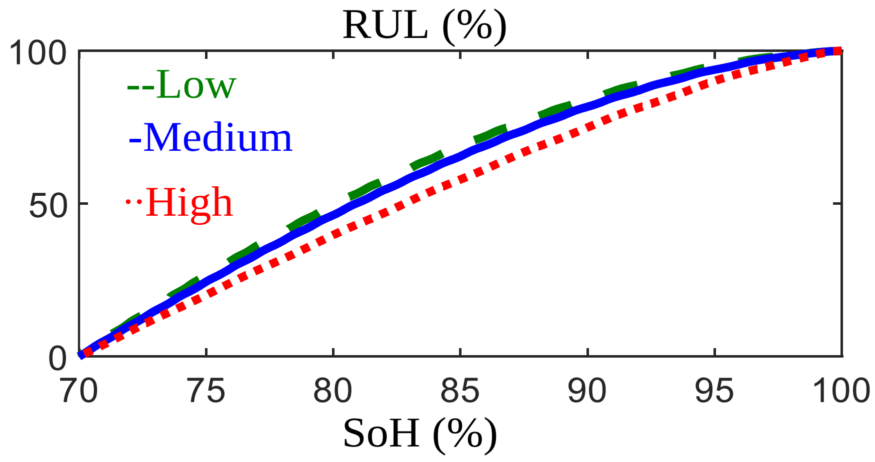
- Large difference in lifetime depending on the usage

- High usage leads to the battery reaching EoL before the vehicle expected lifetime



RUL evolution is extracted form the number of cycles achieved

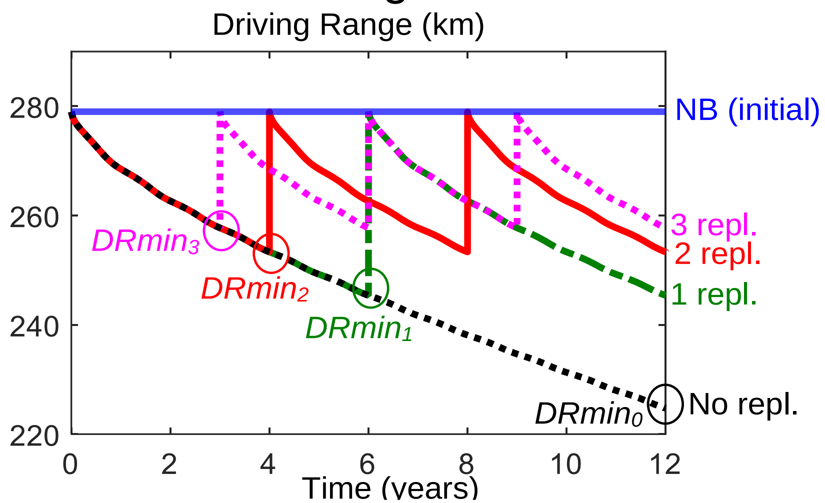
$$RUL(t) = \frac{NFEC(EoL) - NFEC(t)}{NFEC(EoL)}$$



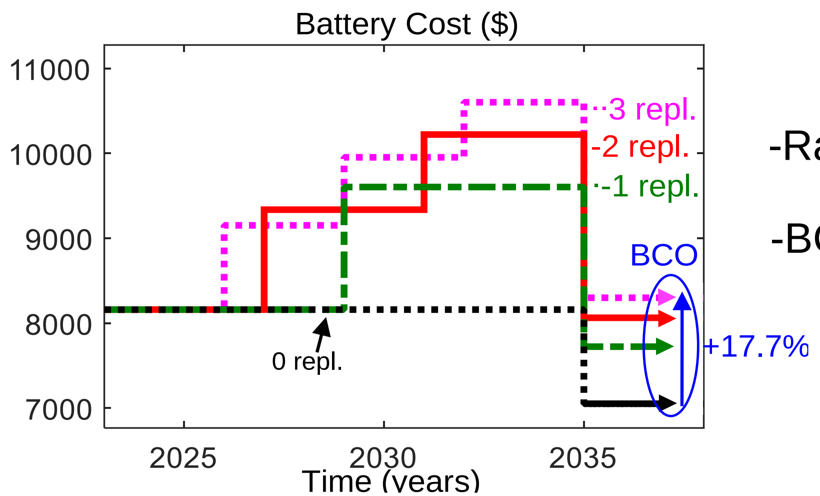
The results of SoH and RUL will be used in the economic evaluation

Appendix : Extended Results for different usage patterns

Example for medium usage



-Driving range restored with replacements

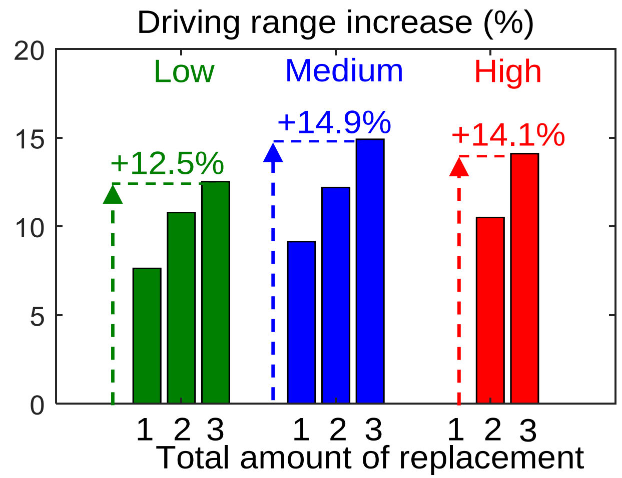


- Moderate increase (higher reselling value for frequent replacements)

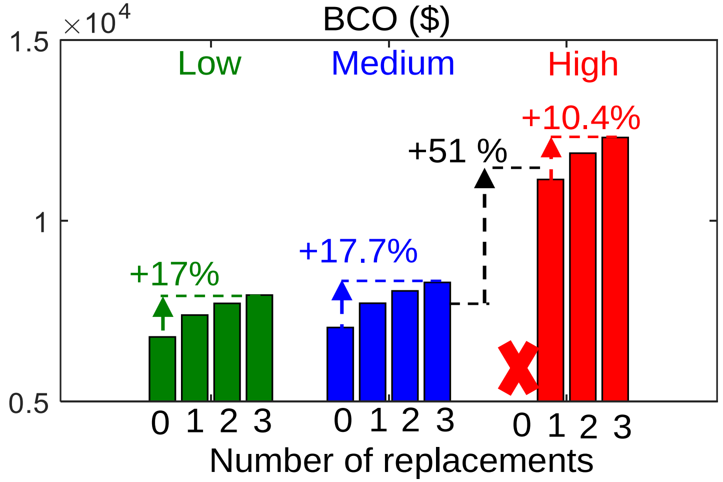
-Range recovery up to 14.9%

-BCO increase up to 17.7%

Multiple usage



-One replacement is mandatory for high usage



-Higher impact of usage than replacements

- Impact of usage on BCO up to 51%

- Moderate BCO increase with replacement