"Techno-Economic Model of Batteries"

Martin Chaud[1], Dr. Ronan GERMAN[1], Pr. Eric Hittinger[2]
Pr. Alain Bouscayrol[1], Pr. Elodie Castex[3]

[1] L2EP, University of Lille, France
[2] Rochester Institute of Technology, Rochester, USA
[3] TVES, University of Lille, France

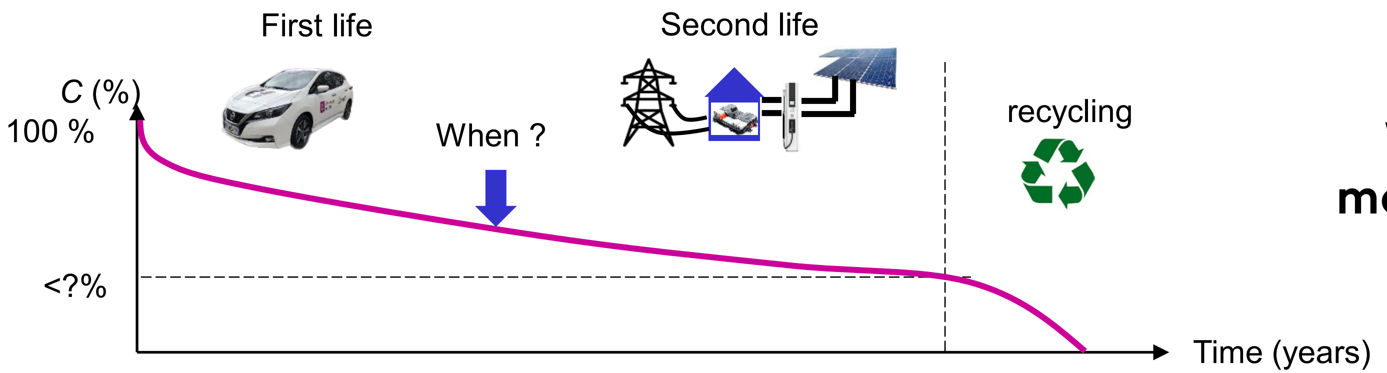
1. Context and objective
2. Technical modelling
3. Economic modelling
4. Case studied and results

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 comprehensive framework

How to predict battery aging?

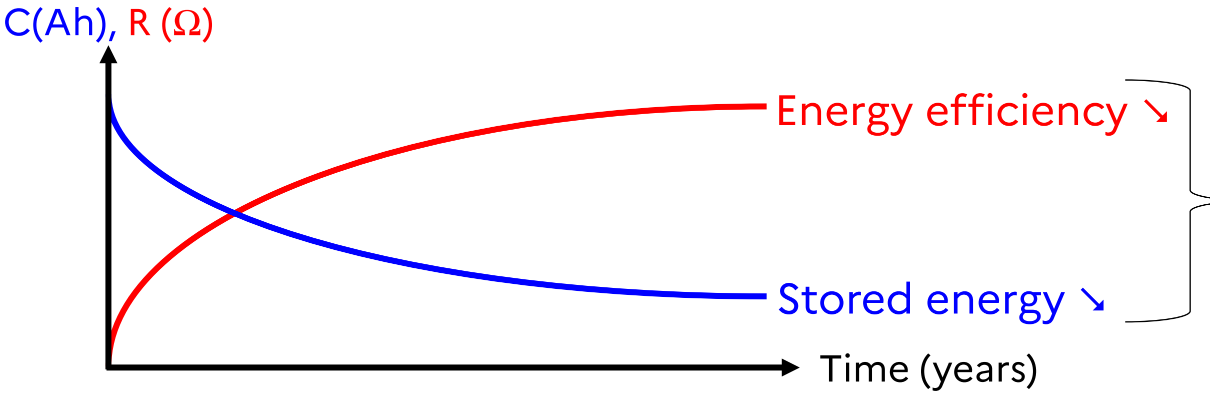


When is the best moment to switch to second life ?

Methodology: Merge battery technical and economic models together

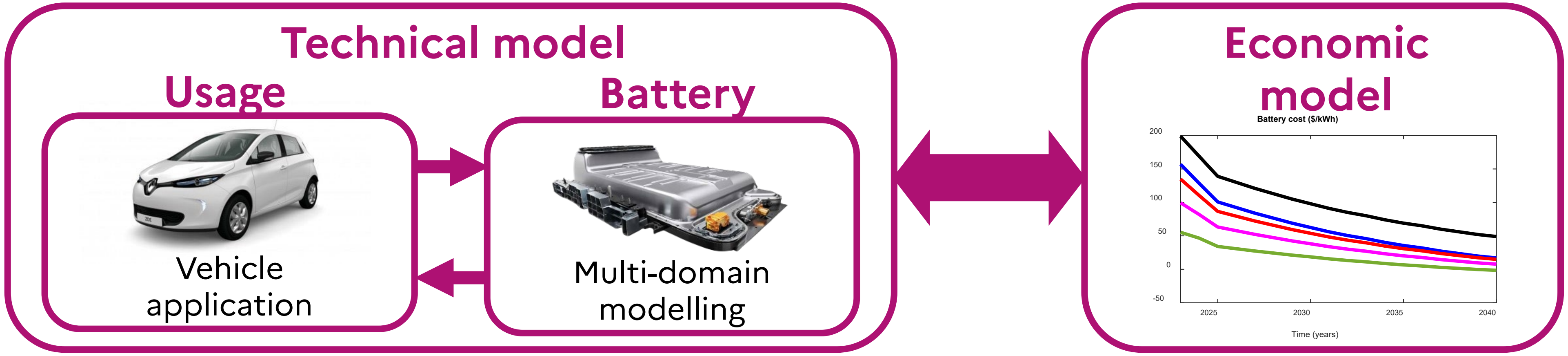
Batteries undergo performances degradation over time ➜ Aging

Battery aging

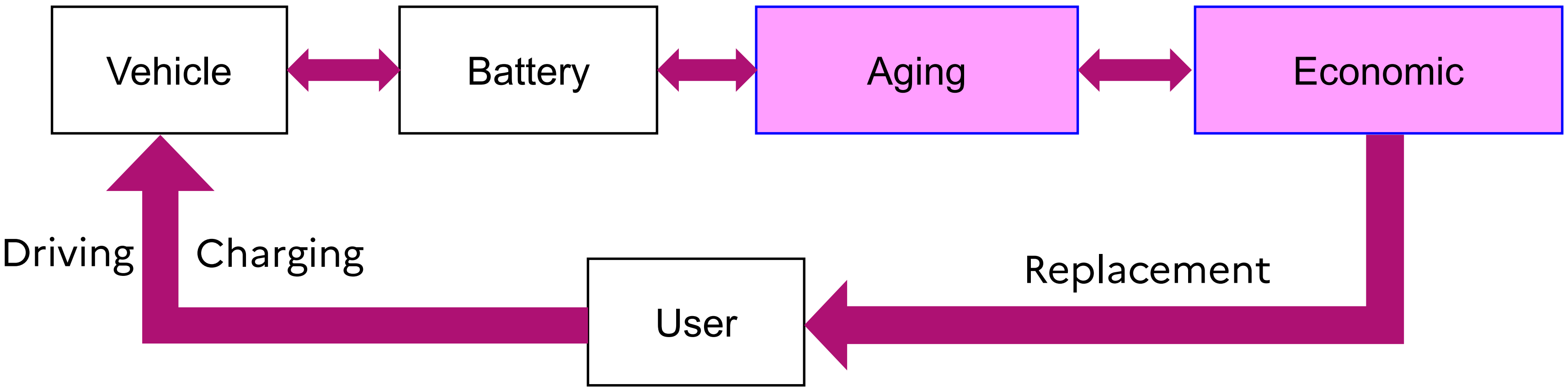


Degradation depends on the usage, impact the price

Global model

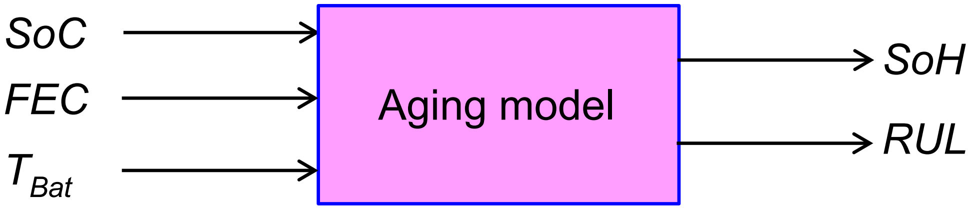


Multiple interactions to take into account



Multi-domain system → Need a unified formalism

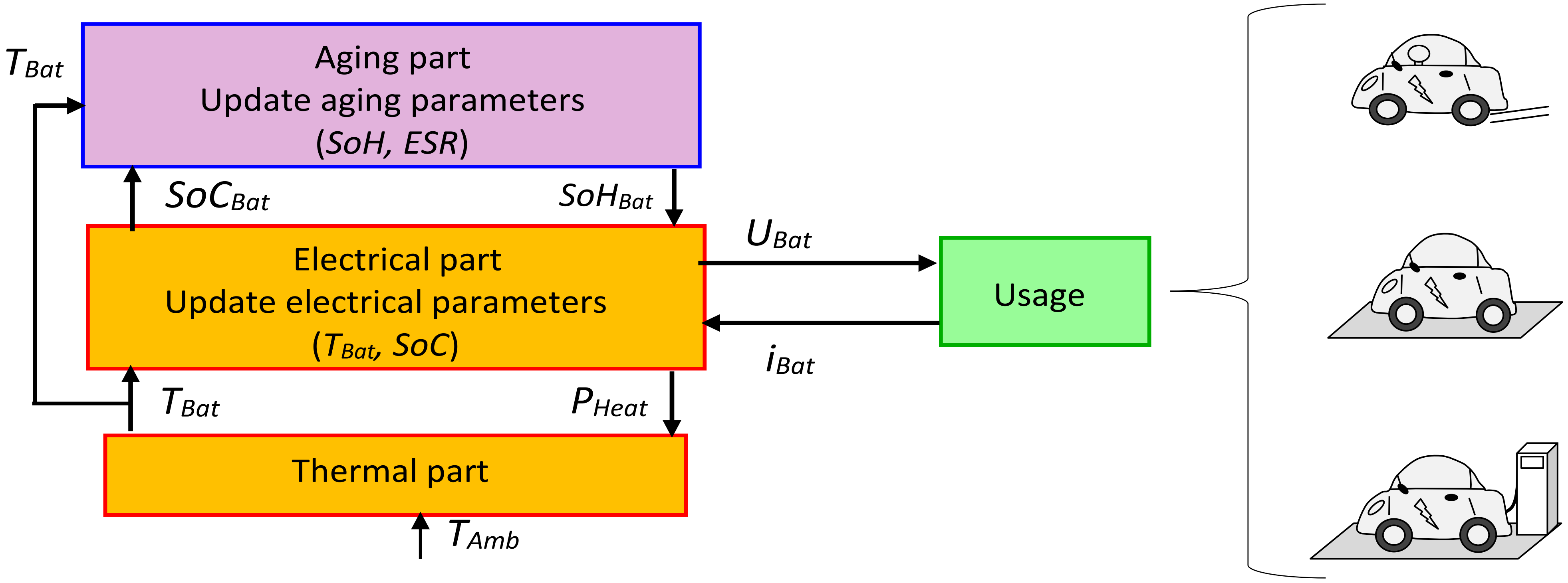
Estimators are used in EMR



Technical Modelling

Battery model

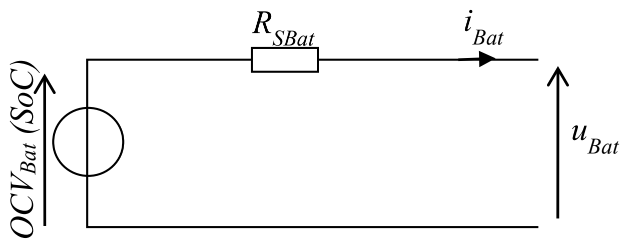
Aging and vehicle usage are taken into account



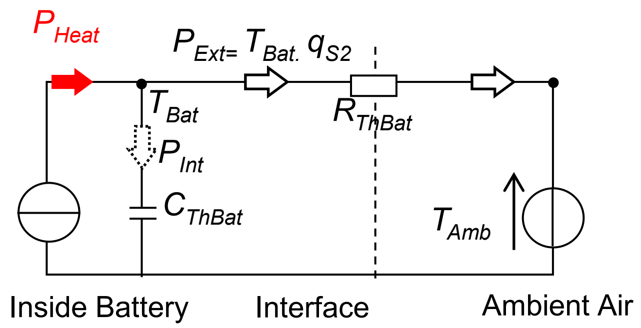
➡ Multi-domain modelling in interaction with the battery usage

Model

Electrical part

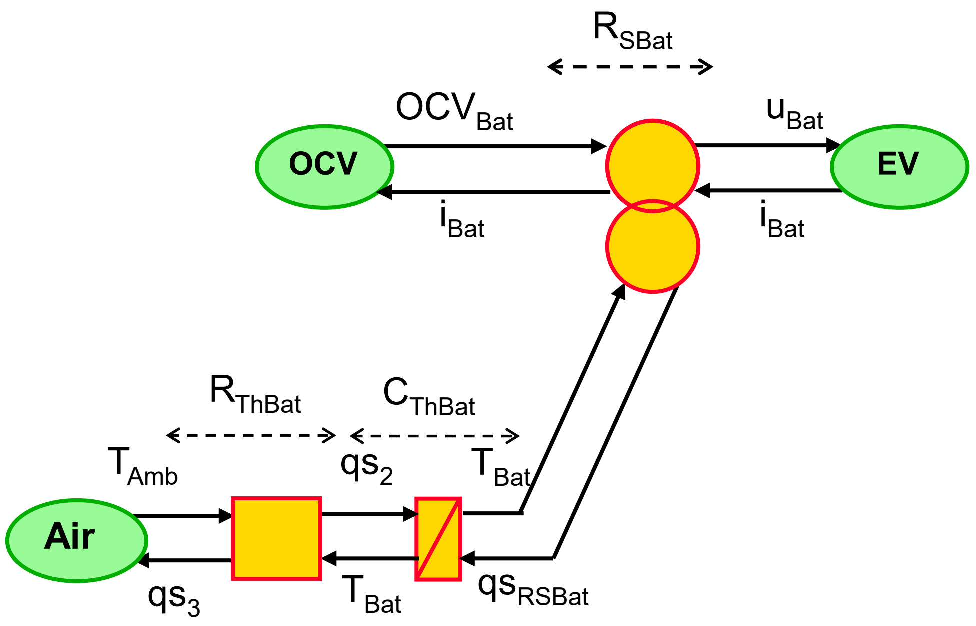


Thermal part



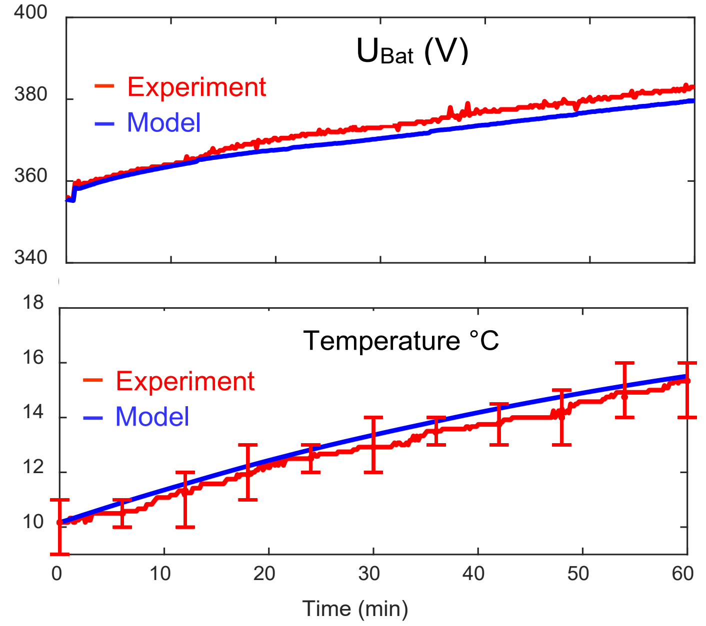
$$P_{Heat} = R_{sBat} i_{Bat}^2$$

Organization : EMR

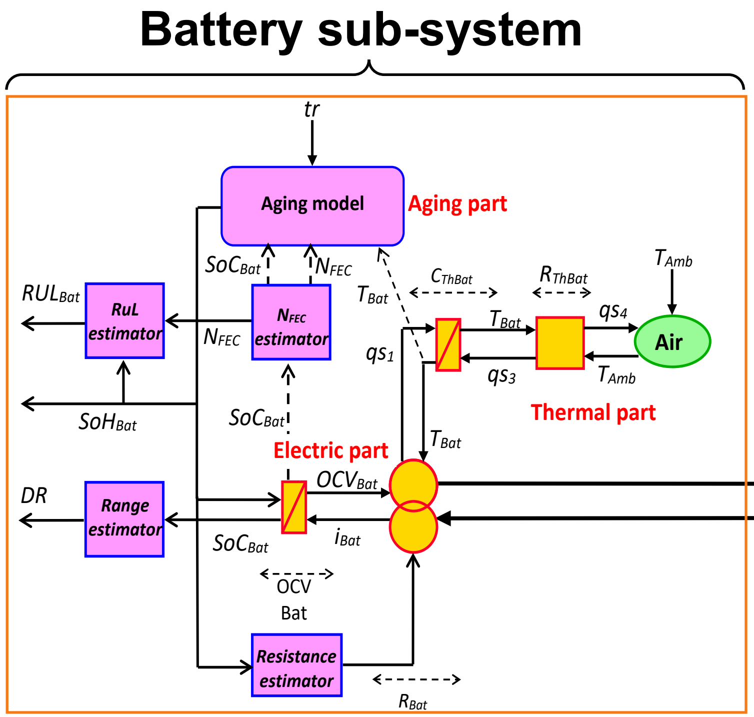


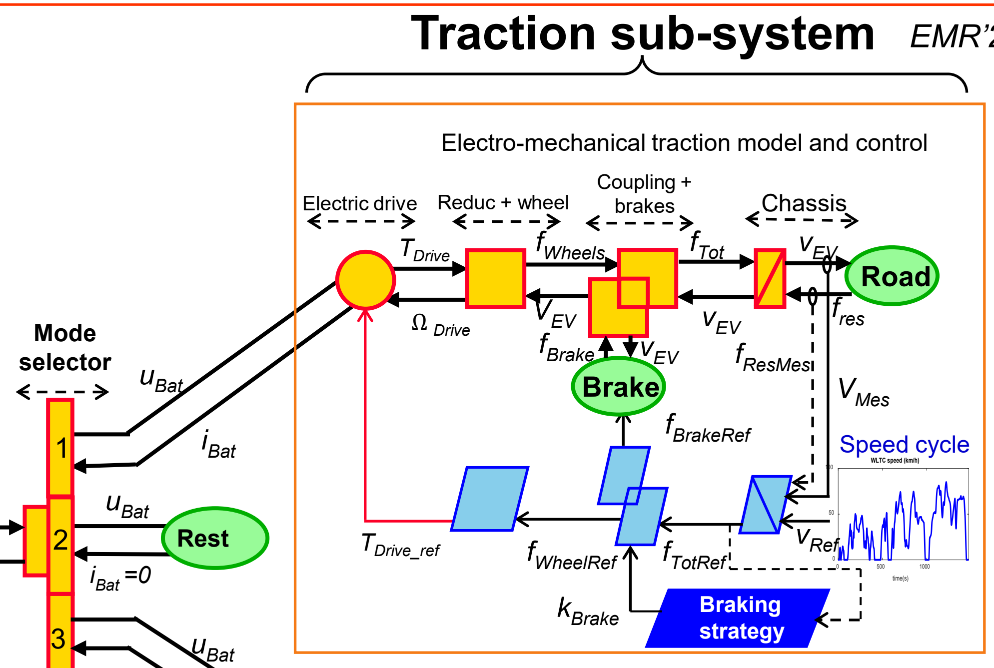
R_{SBat} is the electro/thermal interface

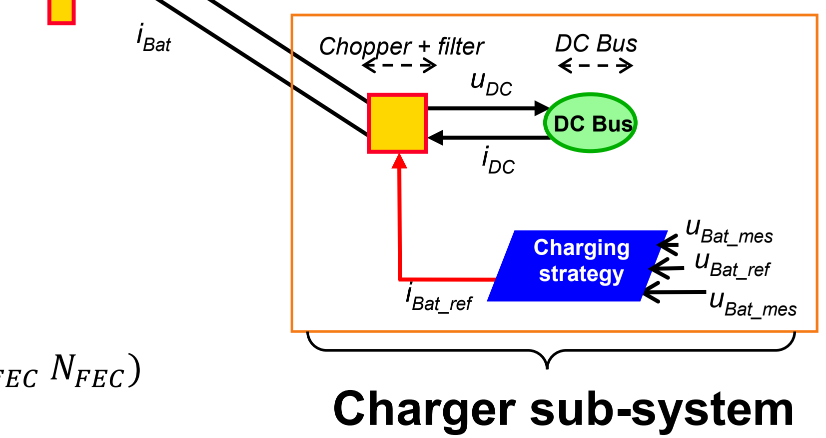
Model validation



Renault Zoe recharge







Outputs:

State of Health **(SoH)**

Remaining Useful Life **(RUL)**

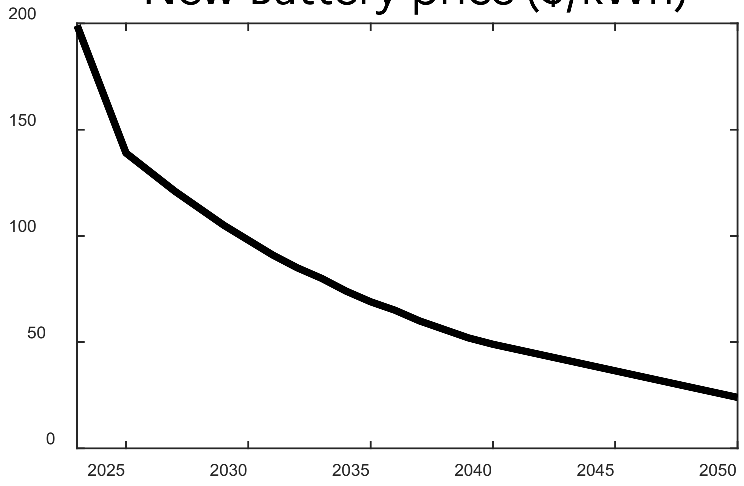
Driving Range

$$SoH_{Bat}(t, N_{FEC}) = 100 - \left(\int_0^t (A + B\, SoC_{Bat}) e^{\frac{-E_a}{k_B T_{Bat}}}\, z\, t^{z-1}\, dt + k_{FEC}\, N_{FEC}\right)$$

$$RUL(t) = 100\, \frac{N_{FEC}(EoL) - N_{FEC}(t)}{N_{FEC}(EoL)}$$

Economic Modelling

New Battery price ($/kWh)



Time (years)

New Batteries prices are decreasing over time

Used batteries prices depends on the price of new batteries at the same time

Used batteries are less performant than new ones due to aging

→ Has to be accounted for in the economic evaluation

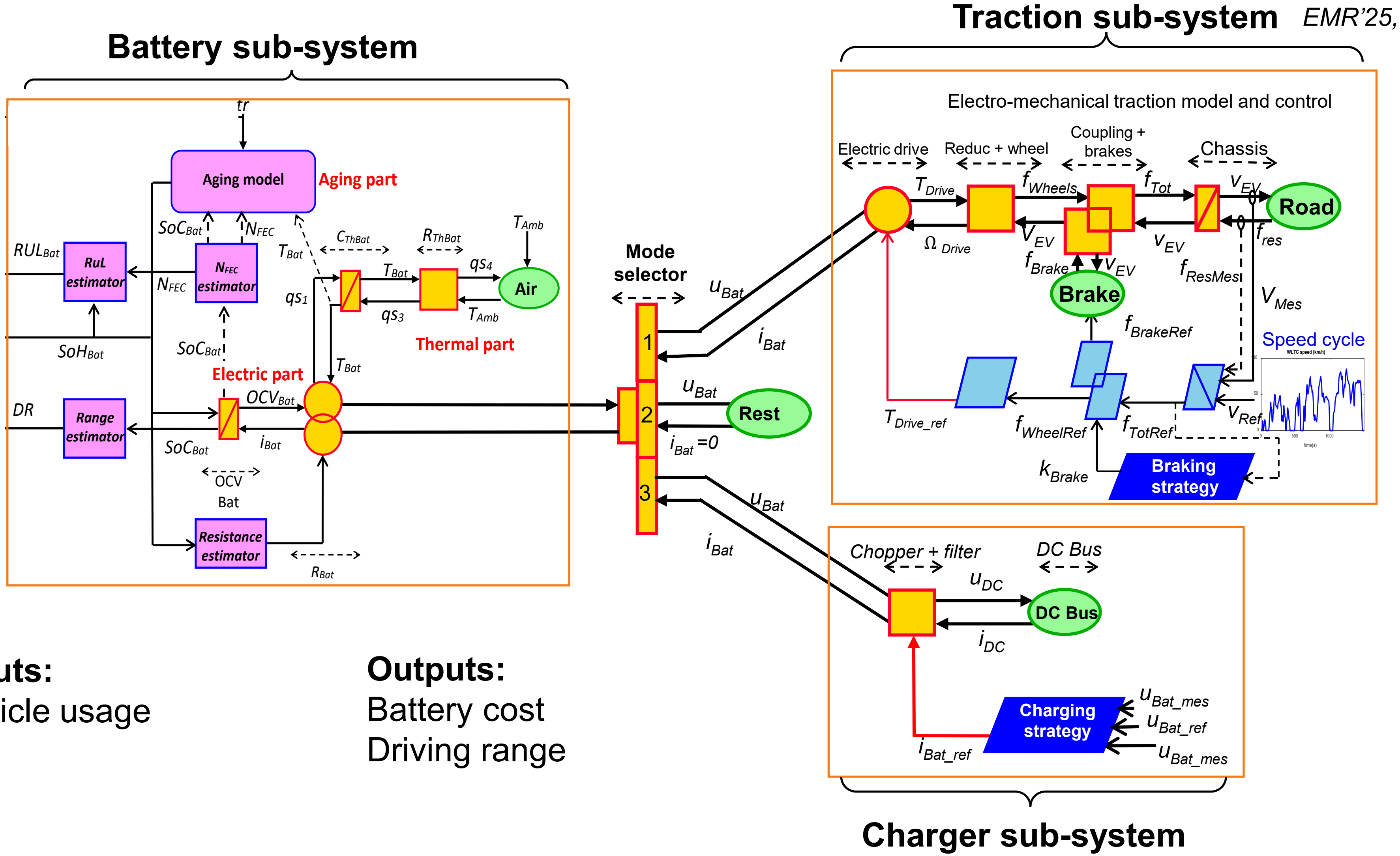
NREL (National Renewable Energy Laboratory), "ATB | NREL," "2024 Annual Technology Baseline,." Accessed: Mar. 27, 2025. [Online]. Available: https://atb.nrel.gov/

SoH: State of Health (%)

RUL: Remaining Useful Life (%)

$$\boxed{Cost_{UsedBat}(t) = Cost_{NewBat}(t)SoH(t)RUL(t)}$$

Techno-Economic Model of batteries



Inputs:
Vehicle usage

Outputs:
Battery cost
Driving range

➡ Estimation of the battery cost and driving range for different replacements

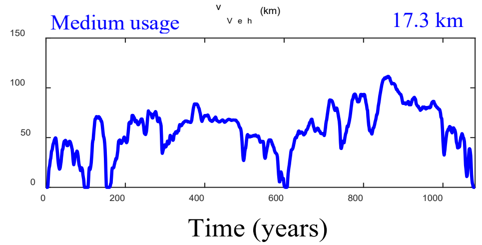
Case studied and results

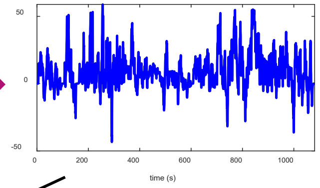
Techno-Economic Model of batteries

A realistic vehicle usage is considered

EMR'25, Lille, July 2025

Vehicle usage is an input for the system



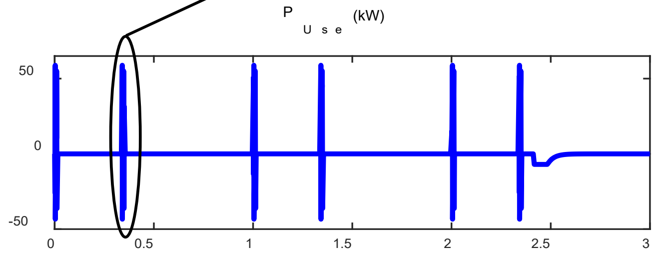


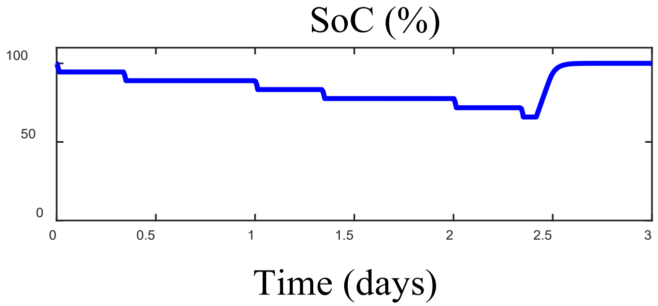
-Two 17.3km/18min drive per day (Artemis extra urban cycle)

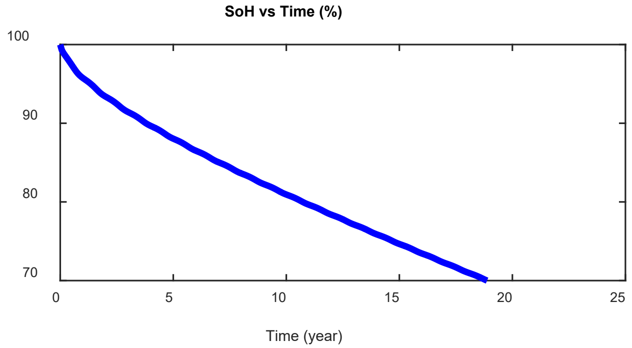
-Full recharge every 3 days

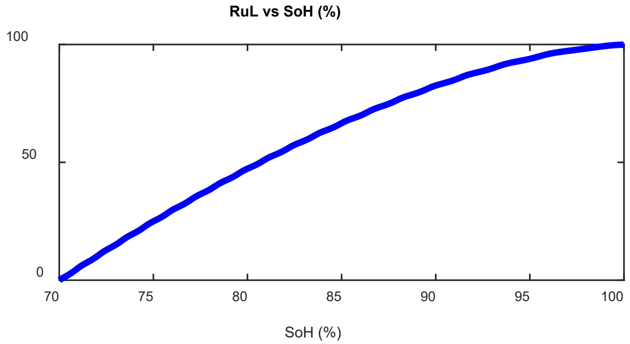
-Yearly ambient temperature from the Lille meteo station (France)

-Simulated until the SoH reaches 70% (End of Life)









Results: SoH and RUL estimation

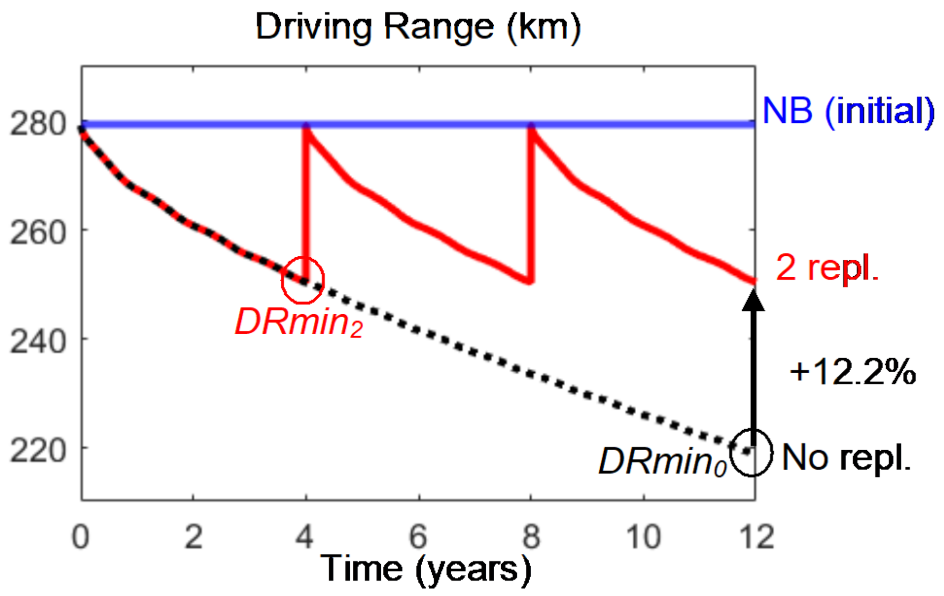
Techno-Economic Model of batteries

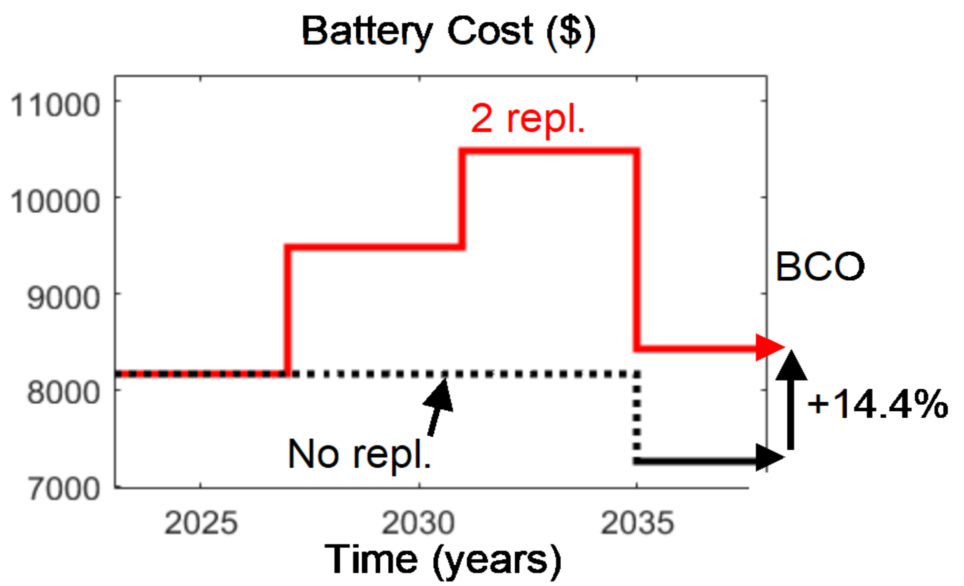
Simulation for 0 and 2 replacements

Used battery is sold when replaced

Vehicle lifetime set at 12 years

Outputs:
Driving Range (km)
Battery Cost of Ownership ($)





Replacing the battery during the vehicles life results in higher remaining driving range and BCO

Conclusion

-Merging of technical and economic model using EMR

-Estimators are used to represent non-energetic domains

-Replacing the battery results in an increase in driving range and cost of ownership

Perspectives

-Taking into account recycling/emissions

-Analysing second life usage

-Integrating used batteries market inputs

Acknowledgement

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

MARTIN CHAUD [1], RONAN GERMAN [1], ERIC HITTINGER [2], ALAIN BOUSCAYROL [1], AND ELODIE CASTEX [3]

[1]Université de Lille, Arts et Métiers Institute of Technology, Centrale Lille, Junia, ULR 2697 - L2EP, F-59000 Lille, France
[2]Rochester Institute of Technology, Rochester, NY 14623 USA
[3]Univ. Lille, ULR 4477 - TVES - Territoires Villes Environnement & Société, F-59000 Lille, France

CORRESPONDING AUTHOR: RONAN GERMAN (e-mail: ronan.german@univ-lille.fr).

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.

WILL (Welcoming Internationals to LiLLe) programme

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» et d'une aide de la Région Hauts-de-France

Région Hauts-de-France

anr agence nationale de la recherche AU SERVICE DE LA SCIENCE

FRANCE 2030

References

[Chaud 2025] M. Chaud, R. German, E. Hittinger, A. Bouscayrol, and E. Castex, "Techno-Economic Impacts of Battery Replacement for Different EV Usage Patterns," IEEE Open J. Veh. Technol., vol. 6, pp. 1650–1660, 2025, doi: 10.1109/OJVT.2025.3574574.

[Chaud 2024] M. Chaud et al., "Study of an EV Driving Range Evolution Considering Battery Capacity Degradation," in 2024 IEEE Vehicle Power and Propulsion Conference (VPPC), Washington, DC, USA: IEEE, Oct. 2024, pp. 1–6. doi: 10.1109/VPPC63154.2024.10755427.

[Desreveaux 2020] A. Desreveaux, E. Hittinger, A. Bouscayrol, E. Castex, and G. M. Sirbu, "Techno-economic comparison of total cost of ownership of electric and diesel vehicles," IEEE Access, vol. 8, pp. 195752–195762, 2020, doi: 10.1109/ACCESS.2020.3033500.

[Ndiaye 2024] A. Ndiaye, R. German, A. Bouscayrol, M. G.-Liseo, P. Venet, and E. Castex, "Impact of the user charging practice on the battery aging in an electric vehicle," IEEE Trans. Veh. Technol., vol. 73, no. 4, pp. 4578–4588, Apr. 2024, doi: 10.1109/TVT.2024.3356116.

[German 2020] R. German, S. Shili, A. Desreveaux, A. Sari, P. Venet, and A. Bouscayrol, "Dynamical coupling of a battery electro-thermal model and the traction model of an EV for driving range simulation," IEEE Trans. Veh. Technol., vol. 69, no. 1, pp. 328–337, Jan. 2020, doi: 10.1109/TVT.2019.2955856.

Thanks for your attention !