ENVIRONMENTAL LIFECYCLE MODELLING WITH NMC AND LFP BATTERY DEGRADATION

What battery chemistry is the most sustainable for a high-use EV application?

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ABSTRACT

Rapid growth of EV use requires investigation and limiting the environmental burdens associated with their lifecycle. A key differentiator are their batteries. Li-ion are the standard technology, however, multiple chemistries are used in the market. As their performance and production varies, this project tried to calculate which of the two major chemistries is more ecological.

A simple spreadsheet model "Antool" was developed to estimate degradation of NMC and LFP batteries under specific usage conditions. The degradation model considers calendar and cycle aging, and it is based on existing published literature and real-world data. The model calculates the lifecycle Green-house gas (GHG) emissions of a vehicle based on its battery chemistry.

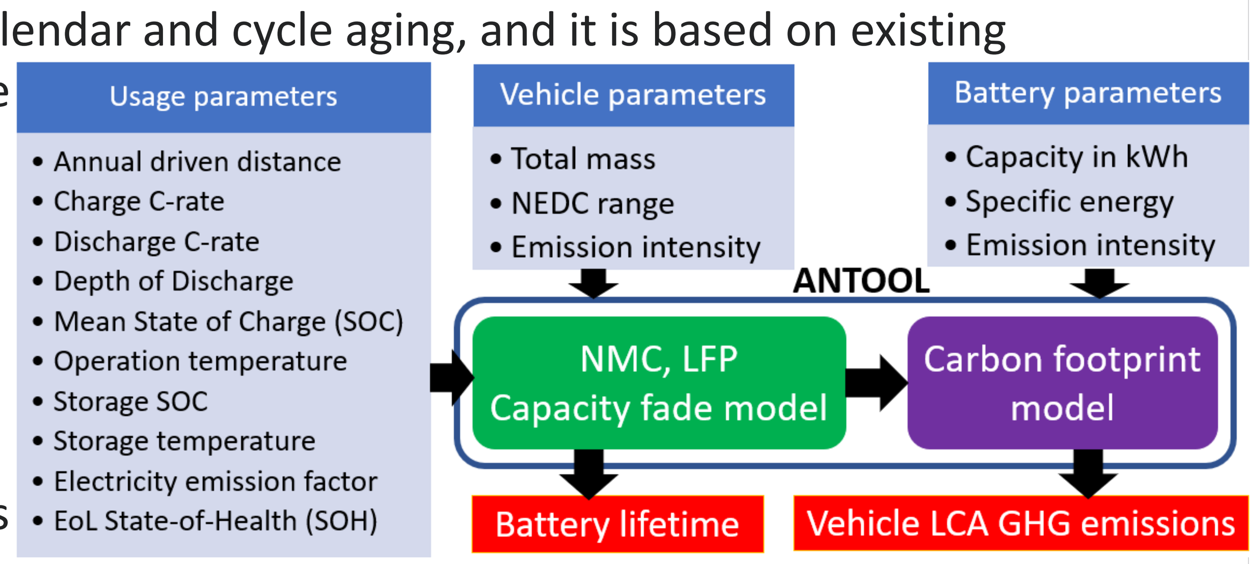

Fig 1: Scheme of the model operation

MOTIVATION

- Different LIB chemistries are competing at the EV market
- **Case study:** Which one is the best fit from LCA GHG emission view for a high-intensity usecase:
  - London based sedan taxi
- Vehicle: BYD Han(Fig2), using LFP "blade" cell-to-pack battery. BYD before used NMC622 in its cars. Are LFP environmentally better?

Fig 2: BYD Han 2020 [1]

METHODS

- Literature sources [3-5], A2Mac1 vehicle database [1], WLTP matlab model [6] and EverBatt tool [2] were used to create a spreadsheet tool with:
  - Production emissions
  - Cycle (Equation 1) & Calendar capacity fade model
  - Use phase emissions
- Tailored to LFP and NMC622 batteries used by Chinese manufacturer BYD in its BYD Tang and Han models

Equation 1 [3]

$$SOH = 100 - \beta \cdot exp\left(k_T \cdot \frac{T - T_{ref}}{T} + k_{DOD} \cdot DOD + k_{Cch} \cdot C_{ch} + k_{Cdch} \cdot C_{dch} \right) \cdot \left[1 + b_{mSOC} \cdot mSOC \cdot \left(1 - \frac{mSOC}{2 \cdot mSOC_{ref}} \right) \right] \cdot FEC^{\alpha_{opt}}$$

RESULTS

The degradation model was developed following the same methodology for generic NMC and LFP. Its results were compared with existing literature tests. The preliminary findings show similar patterns, however, there is a significant variation not captured by the model. The overall R^2 was 0.65 for tests within the input range of the model. It was significantly lower for LFP chemistry tests. The 66 tests are shown on the Fig 3.

Fig 3: Literature vs Model variation, Battery SoH %-point difference (>0% = the Model overestimated the SoH)

- Degradation model general findings:
  - Key degradation drivers are storage & operation temperature and storage SOC
  - Calendar aging is similar for both chemistries
  - NMC is often more impacted by cycle aging than LFP
  - Output lifetime Full Equivalent Cycles range a lot:
    - NMC: 320 - 3500 FECs
    - LFP: 500 - 4200 FECs
- Validation of the degradation model against literature:
  - Outliers in resulting SOH showed limits of the model:
    - Minimum operation temperature 20 °C
    - Mean SOC range: 15-85%
  - For NMC, Antool slightly underestimated capacity fade
- London taxi BYD Han case study (Fig 4, Fig 5):
  - LFP is better (if the vehicle can sustain over milion km)
    - Production GHG: NMC=80; LFP=55kgCO_2eq/kWh[2]
    - Use GHG: small difference due to lower NMC mass

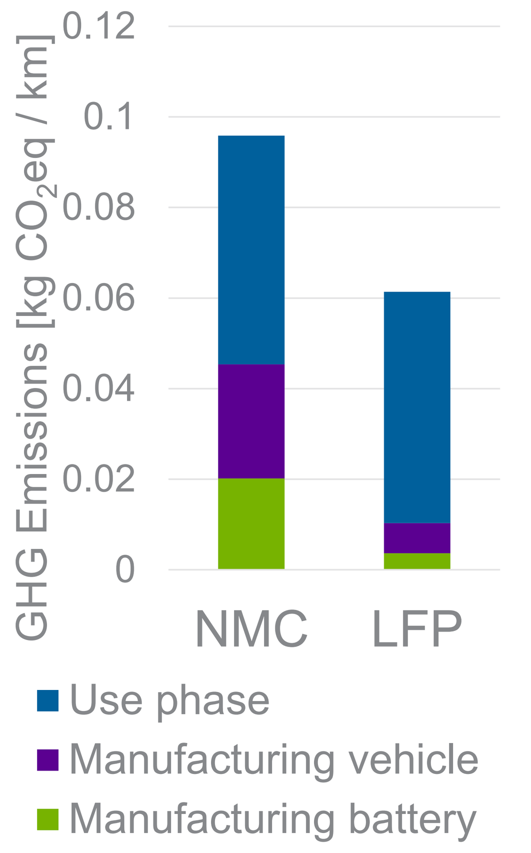

Fig 4: Lifecycle GHG Emissions

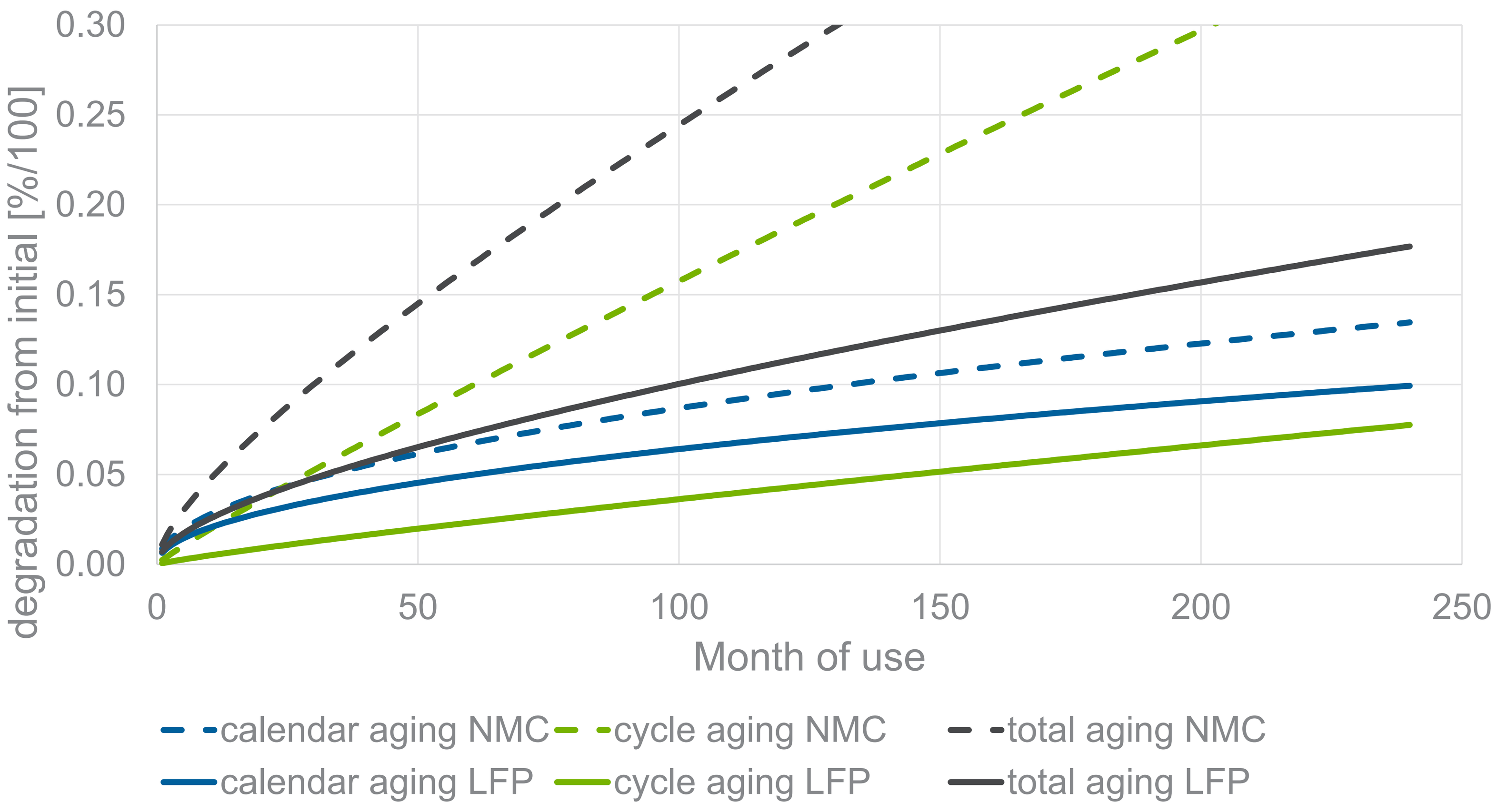

Fig 5: Modelled degradation mechanisms of NMC & LFP for the case study

CONCLUSIONS

Degradation model

Higher cycle life for LFP corresponds to literature [9] in general. For low-use in high temperature environments, NMC battery can degrade slower. Studies used are sources of error of the model.

Model validation

The model can serve as a first-point estimate for NMC batteries. Caution must be taken when using it for LFP due to limited number of studies used in the original model's paper and some inconsistent findings.

London taxi case study

NMC lifecycle range of 300,000 km seems realistic. LFP 1.16m km corresponds well with official 1.2m km[7]. Overall emissions of 61 and 96 grams CO_2eq/km for LFP, NMC is close to typical values in literature [8]

IMPACT / NEXT STEPS

- **Antool model's possible next steps:**
  - LFP cycle aging behaviour to be reviewed
  - Low-use case studies should be produced
  - Validating model's results with experiments
  - Adding End-of-life emissions impact
  - Incorporating Lithium plating aging effects
  - Variable electricity CO_2 intensity addition
  - EverBatt emission data validation as large variation in literature exists
- **Case study findings:**
  - Shows that direction towards LFP batteries can bring large environmental benefits
  - Economic benefits should follow as LFP batteries are typically cheaper [10]

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BIO

Antonin is trying to find ways to help human civilisation to sustain itself. He is studying Mechanical Engineering with Manufacturing and Management at The University of Bath. He wrote his first paper on EVs in 2012, started first research internship in 2014 and co-designed his first car, en EV student formula, recently, while still not having a driving license.
Antonin is interested or involved in sustainability, energy, manufacturing, politics and activism.
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