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Technical Report CEA/DEHT/LV/2023-100

Analysis of the JRC Harmonized rules for the calculation of Carbon Footprint of Electric Vehicle Batteries

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Introduction

CEA and BRGM thank the JRC for the opportunity to share their comments on the *Carbon Footprint of Electric Vehicle Batteries (CFB-EV)* (hereafter CFR).
The CEA and the BRGM support the scientific basis used to establish the requirement for the declaration of the carbon footprint of the batteries introduced in the EU market, in the forthcoming Batteries Regulation. The BRGM and the CEA acknowledge and support the efforts of the European Commission to implement Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA) in European policies over the last 30 years[1]. We support, in particular, the Product Environmental Footprint as initiated through the Commission Recommendation of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organizations.
The present analysis aims at improving the CFR in order to allow easier implementation on the one hand, and better efficiency in promoting low carbon batteries on the other hand. To this aim, we focus on propositions to make the calculation universally applicable to any type of battery and EV application, more representative of the battery itself (including its upstream supply chain and downstream end-of-life), to improve data quality, to reduce ambiguity and probability of circumvention, and to make the calculations and the verifications easier. The modifications we propose are sometimes not consistent with the PEF guidelines, but this is already the case of some of the CFB rules (e.g., concerning the use phase) or even with the compromise, but we aim to stress all the problems that may arise at the time they enter into force.

Functional Unit and reference flow (3)

The functional unit proposed by JRC is consistent with the regulation compromise and PEFCR:
“1 kWh of the total energy provided over the service life of the battery system”.
We agree that we should be aiming to quantify carbon footprint per unit of service delivered.
We agree that we should discourage providers from reducing the lifetime in order to get a better carbon footprint label.
However, the proposed functional unit and calculation methodology **present serious limitations in the framework of battery carbon footprint declaration**.
This functional unit is inversely proportional to the number of cycles that *will be performed* during the battery life. This number of cycles is by definition unknown at the date of manufacture. It is highly dependent on usage (temperature, Crate, SOC window, cycles per year…) and presents a very high variability (~factor 10) which translates into a **huge uncertainty on the final result**.
JRC proposes to calculate the kWh delivered using GTR22 and a conversion between km and kWh. This introduces several biases: GTR22 is only applicable to a subset of vehicles (BEV & PHEV < 3855kg), and the result is **directly dependent on the vehicle consumption**, which is completely out of scope of the battery carbon footprint. A battery does not need to be specifically designed for a given vehicle. Finally, this introduces an **unfair comparison** between batteries subject to GTR22 and others, which will be evaluated according to ‘cycling in reference conditions’. It is important to note that cycling in a laboratory is not representative of real-life ageing, and small variations in cycling conditions can lead to large variations in cycle life.
Furthermore, the durability of an EV battery is not only limited by cycle life, but also by calendar life which is especially the case for classical usage. Only for intensive use such as taxis, rental cars, ridesharing companies, will cycle life be limiting. **The calculation based exclusively on a number of cycles is therefore biased**.
More details and pathologic examples of these shortcomings are available in

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[1] Sala, S., Amadei, A.M., Beylot, A. et al. The evolution of life cycle assessment in European policies over three decades. Int J Life Cycle Assess 26, 2295–2314 (2021). https://doi.org/10.1007/s11367-021-01893-2

Annex II: Functional Unit shortcomings. Note that **these examples could represent a significant part of the market in the future**.

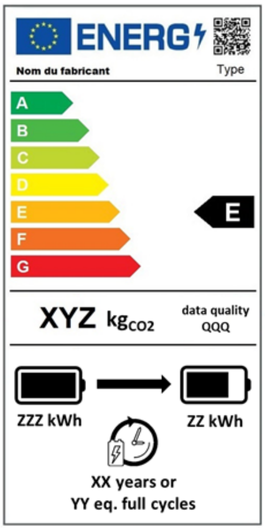
Finally, the use of a lifetime in the functional unit and reference flow (sometimes a conventional lifetime like 50 years for buildings) is only necessary when the scope includes both production phase and use phase. In this case, the lifetime acts as a weighting parameter between both phases. Here, as the use phase is excluded, we consider that the use of lifetime is not necessary.

However, as stated initially, it is important to discourage providers from reducing the battery lifetime.

Therefore, we propose the functional unit « produce [and recycle] 1 unit of battery » and 3-fold labelling:

- **Total carbon footprint for 1 unit of battery**
- **Battery certified lifetime in years *and* full cycles equivalent (first limit reached)**
- **Initial SOCE and SOCE at end of life**

Here is an example of a possible labelling (in addition to other requirements of the regulation):



calculated from
XYZ / ZZZ

Initial SOCE (ZZZ) and SOCE at end of life (ZZ) can be defined and controlled according to GTR22, with no need to make assumptions on the battery usage or on the vehicle consumption.

In certain cases, the vehicle manufacturer will be able to convert from kWh to km, but this is an independent topic, not under control of the battery manufacturer.

Separating lifetime from carbon footprint avoids multiplying uncertainties and brings more transparency.

The choice to present total carbon footprint per 1 unit of battery and not per kWh of SOCE is an incentive to avoid oversized batteries. However, classes of performance and thresholds are defined by dividing this footprint by the battery capacity in kWh, which avoids the risk that dividing a ‘F’ battery into several subparts may lead to ‘A’ batteries.

System Boundaries (4)

The JRC sets the system boundaries in section 4 of the report; the inventory detailed in the Annexes gives a better understanding of the components included/excluded from the scope.

In the JRC report, it is not clearly specified whether to consider the infrastructure: “manufacturing of equipment (capital goods) may be excluded”. It is rarely mentioned or modelled in the literature, when it is, proxies are often used and no explanation on the calculation is given. Some authors decide to completely exclude it by saying that impacts are relatively small compared to the overall impacts of the battery[2]. However, we calculated (

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[2] PELL, R. and LINDSAY, J., J. Comparative Life Cycle Assessment Study Of Solid State And Lithium-Ion Batteries For Electric Vehicle Application In Europe, *Transport & Environment*, 2021.

Annex III: System Boundaries) that the impacts due to the infrastructure could represent around 10% of the GHG emissions. At the same time, they are very difficult to estimate following LCA principles, and perhaps not very different between factories.

Therefore, we recommend that JRC clearly specifies one of the following options, from the most to the least preferable:

- **To calculate the infrastructure carbon footprint from the depreciation of capital and a monetary emission factor** to be defined **for the country of the factory**
- **To keep the infrastructure out of the scope** until a reliable methodology is defined
- Alternatively, to include the impacts of a mean typical factory

The JRC proposes not to consider at all the use phase. The electricity used to power the motor is indeed not product dependent and should not be considered according to EC recommendation 2021/2279 annex II.4.4.7. However other consumptions are product dependent and should be included:

- Round-trip internal losses
- Overconsumption of the vehicle due to battery mass
- Overconsumption of the vehicle due to battery own needs (cooling or heating in particular)

In practice, they can induce a significant CF, but it is very dependent on the vehicle and on the use phase electricity mix, which is not known at the date of battery manufacturing. Therefore, we propose **to keep roundtrip losses and overconsumption outside the CFB calculation** but insist on the **importance of mandatory performance requirements for EV batteries** (while they have been excluded from the EU2020-0353 compromise).

It is not very clear in the proposal if company-specific data are mandatory for the active material synthesis step. As NMC synthesis alone accounts for 16% of the total footprint vs 19% for cell and pack manufacturing[3], **we recommend making it clear that active material synthesis also requires company-specific data.** It would be easier to split Table 4 between active material synthesis and electrode fabrication, as they are often located in different plants.

We also recommend:

- **To specify that the inverter is excluded, like the charger**
- **To specify that the junction box is included**
- **To include only the heat transfer fluid and pipes that are contained in the battery pack, up to the plug and exclude all other parts of the heat management system of the vehicle**
- **To include transport of inputs in all LCI tables, but not create a distinct life cycle phase**

More details on the rationales for these recommendations about the system boundaries can be found in

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[3] Dai, Q., Kelly, J. C., Gaines, L., and Wang, M., Batteries 2019, 5, 48; doi:10.3390/batteries5020048

Annex III: System Boundaries.

• Company-specific activity data and elementary flow collection requirements (6.2)

The CF Rules lack prescriptiveness regarding inventory data collection and reporting, namely regarding

- list of activity data to be collected as per Tables in Annexes 1 to 3
- associated use of secondary datasets (to model associated upstream impacts)

As such, we consider that the current draft version of the CF Rules does not entirely create the conditions for a level-playing field, potentially leading to different interpretations of these rules. We recommend that the JRC amends the current draft version in order to make rules unambiguous, and inventory data collection and reporting complete.

In particular, **we recommend that the "Data collection requirements", as developed in Annexes 1 to 3 and in particular in Tables 3 to 9, are clarified. This revision shall include i) a larger level of details and of prescriptiveness in the list of activity data to be reported; and ii) a clear link between the activity data to be collected and some EF-compliant secondary datasets recommended to be used** (where appropriate, i.e., where LCDN data shall be used). We suggest that in order to make these clarifications, the JRC builds on current draft version of the PEFCRs, which are more prescriptive regarding Data collection requirements (more detailed collection templates, with prescriptions on default datasets to be used). We recommend not to forget the leaks of methane wherever it is used in the process, preferentially in the form of a default value.

Hierarchy for the selection of secondary datasets (6.3)

We are concerned that incompleteness of the LCDN database (missing datasets) and some imprecisions/underestimations in standard LCI datasets may alter the quality in the results of the CF calculations, to an extent that is difficult to quantify at this stage but that is most probably significant. Incompleteness in the current version of the LCDN in particular relates to the absence of datasets regarding production of lithium carbonates and hydroxides; battery-grade graphite, either natural or synthetical; cobalt compounds (hydroxides, sulphates, etc.); nickel compounds; battery precursors; etc.

Moreover, recent scientific literature on the LCA of the production of some battery raw materials (e.g., battery-grade graphite, lithium carbonates from brines) showed that inventories, including in standard LCI databases, may have so far led to underestimated CF (as detailed in Annex VI).

We therefore recommend the following actions:

1) **Limitations in the LCDN, in particular regarding battery raw materials, shall be better highlighted and acknowledged. Improvement needs** shall be included **in the first version** of these CF Rules and in the planning of **updates;**

2) the JRC shall increase completeness of datasets in the LCDN, in particular including secondary datasets regarding primary battery raw materials production;

3) when completing the LCDN with additional datasets relative to primary raw materials production, the JRC shall ensure the highest level of quality possible. This implies the following recommendations:

> **- the JRC shall pay particular attention to avoid underestimating CF of primary raw materials in the LCDN;** which would subsequently disincentivize the use of primary data, failing to drive the market towards larger reliability of CF values, and any support actions towards reducing this footprint.
>
> **- the JRC shall assess the opportunity to provide regionalized datasets,** at a level of granularity to be defined. This may be relevant in particular for several cases of **battery raw materials (lithium, graphite, etc.), for which geographical and technological diversities in the production imply diverse CF**; in a context where inventory data may be accessed either from recent scientific literature or recent studies from industrial associations (see Annex VI);

5) Finally, we recommend that the **JRC and the EC clarify potential interlinks with ongoing and upcoming**

standard and legislative initiatives, and in particular:

i) how the LCDN will be **complemented,** and potentially **updated, through Environmental Footprint data compiled in the context of the "CRM Act";**

ii) how the JRC CF Rules will **interlink with standard systems for sustainable mining (potential alignment/misalignment).**

Data quality requirements (6.4)

We recommend that the two key output pieces of information from the implementation of the CF Rules **are explicitly reported (i.e., labelled, and not reported in the CFB supporting study):**

- **the CF value and/or class of value;**
- **the quality associated with the assessment (i.e., the DQR value associated with the calculated CF).**

See for example the label proposed in Functional Unit and reference flow (3).

From a scientific perspective, it is crucial that the CF is informed with its associated level of uncertainty. From the perspective of the CF Rules' implementation, it is crucial that the DQR is adequately used to drive the value chain towards a higher quality of results. Labelling the DQR value in addition to the CF will incentivize the use of data with higher quality (as reflected with lower DQR).

Moreover, we acknowledge that the DQR as presented in this EC Recommendation is the result of a compromise, and as such we do not recommend amendments of the DQR calculation approach in the short-term; but in a medium term.

We recommend that, by a time horizon to be defined (e.g., 5 years), the JRC and the EC explicitly plan a revision of section 6.4 Data quality requirements. As further detailed in Annex VII, this revision shall in particular include:

- **increasing the level of requirements (i.e., of constraints) for those data referred to as of Good, Very Good and Excellent quality**, both regarding company-specific datasets and secondary datasets.
- **creating additional sub-categories (i.e., intermediates to Fair, Good, Very Good, etc.) in order to better differentiate between levels of uncertainties.**

Improvement needs shall be included in the first version of these CF Rules and in the planning of updates.

End-of-Life and Recycling (6.6)

In the JRC report, it is specified that the Circular Footprint Formula (CFF) must be used in order to model end-of-life (EoL) of products and recycled content. The definition and the default values of the parameters of the CFF chosen by the JRC raise several limitations such as:

- The high weight given to EOL recycling that will occur in 15 years and is highly prospective,
- The compensation of 76% of impacts of raw materials by future, possible, avoided emissions
- The risk of resource shuffling for commodity materials (see

- Annex I: Resource shuffling),
- The gaps in recycling datasets,
- The multi-functionality of recycling,
- The quality of outgoing secondary material.

These limitations are explored in more detail in

Annex IV: End-of-Life and Recycling.

Following these observations, we suggest that JRC specifies a methodology that focuses on the beginning of battery life, which is under direct control of the manufacturer at the time of declaration.

- Preferably **a cut-off method**, as recommended by the BatteryPass consortium and the Global Battery Alliance. It is the simplest method to apply and verify.
- Alternatively, keep the Circular Footprint Formula but assign **a high value to A** (0.8).

To limit resource shuffling, we recommend using **R_1 inferior or equal to the country mean value** of recycled content for commodity materials (aluminum and steel, list to be updated by the EC). We also recommend **including a more realistic collection rate in R_2** and defining a consistent value for lithium.

Moreover, we recommend **updating the LCDN with datasets for recycling processes**. As some of these will be prospective, the JRC should **revise the DQR criteria** in order to better evaluate future/prospective processes.

In the present form, due to the multi-output nature of recycling processes, and the fact that the term $E_{recycled}$ (E_{rec}) is associated to a single material, the CFF may be applied differently in different JRC CF Rules' compliant studies. Thus, we recommend that the JRC **specifies the approach to solve this multi-functionality issue** associated with the term $E_{recycled}$ of the CFF, in a dedicated section of the report.

Quality of recycling is not considered with sufficient details. The CFR consequently fail to reward (and incentivize) high quality recycling, without any proper consideration of the actual quality (e.g., presence of impurities) of outgoing secondary materials. Therefore, we recommend that the JRC **provides a unique, standardized, approach for the calculation of company-specific quality of outgoing secondary materials (Qs_{out})**, and additionally **gives default values for all relevant materials**. In doing so, the JRC shall build on its recent work[4] on the quality of recycling, with extension from plastics.

Allocation rules (6.7)

We acknowledge that the decision hierarchy as in EC Recommendation 2021/2279 (Annex I – section 4.5) to model systems involving multi-functionality of processes is the result of a compromise in the context of the PEF developments. We understand that section "6.7 Allocation rules" in these CFR refers to the general PEF recommendation, and as such complies with the Batteries Regulation. However, we recall that, as demonstrated in recent scientific literature[5], clear rules on allocation in case of metals co-production is essential to ensure the conditions for a level-playing field. We are concerned that Section 6.7 instead creates the conditions for potential diverse implementation of allocation rules (please see the main recommendations below, and further details in Annex VIII)

- **Economic allocation in processes where base metals and precious metals are in the output (6.7.1)**

Firstly, "Section 6.7.1 Economic allocation in processes where base metals and precious metals are in the output" shall instead either refer to "metals" in a more generic way, or if only some metals are actually targeted, the rationale shall be made explicit, and **the list of metals targeted by this allocation rule shall be unambiguous**. This implies in addition **clarifying the sentence lines 478-480,** which may leave room for diverse interpretations.

Moreover, Section 6.7.1 is globally not prescriptive enough, while the associated workload may be unnecessarily heavy for making the CF calculations. There exist diverse sources for prices data, as already

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[4] Tonini, D., Albizzati, P.F., Caro, D., De Meester, S., Garbarino, E., Blengini, G.A., 2022. Quality of recycling: Urgent and undefined. Waste Management 146, 11–19. https://doi.org/10.1016/j.wasman.2022.04.037

[5] Lai, F., Laurent, F., Beylot, A., Villeneuve, J., 2021. Solving multifunctionality in the carbon footprint assessment of primary metals production: Comparison of different approaches. Minerals Engineering 170, 107053. https://doi.org/10.1016/j.mineng.2021.107053

acknowledged in the LCA field[6]. **We recommend that the JRC provides unambiguous default values of allocation keys for implementation of CF calculations**, potentially building on existing reference work on this topic[7]. These default values **should be used in the same way for primary and secondary datasets**.

- **Adding a clarifying section in Section 6.7**

Section 6.7 in the document reports the general Allocation rules to be followed when calculating the CF and specifies further some rules for certain types of systems/stages (in sub-sections 6.7.1, 6.7.2 and 6.7.3). **We recommend that the CF Rules additionally specify allocation rules i) in the case of battery-grade lithium production from geothermal brines**, and **ii) in the case of graphite**, whose co-products (and their potential for substitution on the market) are unclear so far in LCA practice (see further details in Annex VIII). In both cases, the JRC CF Rules shall bring clear and unambiguous allocation rules to enable a level-playing field.

Electricity modelling (6.8)

JRC proposes several options for electricity modelling, in hierarchical order: on-site electricity generation, supplier specific electricity product guaranteed by contractual instruments, supplier specific mix, country residual consumption mix, and country average consumption mix.

Considering that:

- The physical tracing of electricity is extremely difficult and not performed in existing grids,
- The electricity travels on average 100 km in the transport network (French example, the figure is increasing)
- Existing contractual instruments are flawed by time and space inconsistencies, and lack of universality,
- Even a perfect traceability and uniqueness of claim would not avoid circumvention by resource shuffling (see

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[6] Ardente, F., Beylot, A. & Zampori, L. A price-based life cycle impact assessment method to quantify the reduced accessibility to mineral resources value. Int J Life Cycle Assess 28, 95–109 (2023). https://doi.org/10.1007/s11367-022-02102-4

[7] https://www.mineralinfo.fr/fr/securite-des-approvisionnements-pour-leconomie/clefs-danalyse-des-marches-de-metaux

- Annex I: Resource shuffling), until *most of the electricity market of the country* is covered by similar regulations, which is unrealistic before several decades.

We recommend only allowing the following hierarchy to model electricity input of the factory:

1. **Average consumption grid mix for the amount sourced from the grid and read on TSO or DSO counter**.
2. **On-site electricity production, only:**
    a. **If the production asset is borne by the same entity as the factory, or the production asset has a direct connection to the factory and is not connected to the grid.**
    b. **For the fraction of the consumption that is not sourced from the network.**
    c. **No credits of any kind can be granted for electricity produced in excess and sent to the network.**

This proposition is consistent with the requirement of uniqueness of claim (as every consumer uses the average consumption grid mix) and avoids resource shuffling since the first year of application.
More details are available in

Annex V: Electricity modelling.

What's more, EF3.1 consumption grid mixes are outdated and sometimes inconsistent[8]. **We recommend updating and completing EF datasets with recent values of average consumption grid mixes**. These consumption mixes should be calculated from the production grid mixes in each zone and the imports/exports between zones via a flow tracing method such as the one used in electricitymap[9].

Further improvements can be proposed for future updates of the CFB.

- Geographic : the grid zones today are countries. Ideally, the size of these zones should be consistent with the length travelled by electricity on the networks, between 100km and 1000km. A bidding-zone level could be relevant for EU (as in the delegated act for hydrogen production[10]), and a subdivision of large countries could be desirable as long as the necessary data is available. The non-interconnected zones (islands) should have their own consumption grid mix distinct from the main network.
- Temporal : as TSOs implement the necessary data, the average consumption grid mix should be used at an hourly timestep rather than a yearly timestep.

Verification and validation techniques (7.3)

CEA and BRGM acknowledge that strict verification rules are welcome to avoid overoptimistic CF declarations. The proposal for a regulation concerning batteries from January 18, 2023, and EC Recommendation 2021/2279[11] gives detailed requirements about the « notified body »; as requirements for this verification of the carbon footprint calculation looks like a complete critical review, which needs to be realised by experienced and skilled people, we recommend adding a reference to XP ISO/TS 14071 standard (2014) for LCA reviewers' skills.

The present text states that the notified body shall check that « Any calculations performed do not include significant mistakes ». Either the sentence should be deleted, or "significant mistake" should be clearly defined (e.g., <5%?). We therefore recommend that the nominal formulae and the nominal results should comply to the described formula, and **the notified body shall make relevant comments about the data quality analysis, as DQR along the supply chain is a key point.**

The JRC rules specify that a visit of the production site(s) shall be organised for company-specific data. However, at the production site of batteries, the notified body will see only the assembly lines, but not the recycling process (except in case of an integrated company) neither the different mining nor other upstream operations. Thus, **we recommend that, in case specific data are used for the suppliers of the declarant, the CFB declarant shall get a complete traceability file from his different suppliers.** We recommend clarifying that a notified body shall perform the same verifications at the supplier premises, unless they were already performed previously (e.g. a material producer may supply various battery manufacturers but needs to be audited only once).

We in particular recommend that the JRC amends section 7.3 to mention the potential of geochemical traceability techniques to verify and validate the data used to calculate the CF (in Section 7.3), not only for the recycled content (for which "traceability" is explicitly mentioned in the text, in Section 6.6.1) but more generally for all primary and secondary raw materials (see further details in Annex IX). In addition, **we recommend that this document explicitly refers to an update of the CF Rules regarding, among other topics,**

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[8] consumption grid mix, FR (93.3g/kWh) > residual grid mix, FR (81.3g/kWh), while consumption grid mix value should be lower.

[9] https://www.sciencedirect.com/science/article/pii/S2211467X19300549

[10] Delegated regulation on Union methodology for RFNBOs, Directorate General for Energy, 2023, https://energy.ec.europa.eu/delegated-regulation-union-methodology-rfnbos_en

[11] Corrigendum to Commission Recommendation (EU) 2021/2279 of 15 December 2021 on the use of the Environmental Footprint methods to measure and communicate the life cycle environmental performance of products and organisations, 2022, *Official Journal of the European Union* L 471 of 30 December 2021

the potential use of these geochemical traceability techniques, in a time horizon to be defined (e.g., 5 years). This update is expected to account for the potential of these techniques at this time horizon (e.g., as developed in the context of Horizon Europe projects and follow-ups).

It will be very difficult and possibly very subjective for the notified body to evaluate how far the non-disclosed information of the CFB can change the carbon footprint. The declarant will argue that he needs to keep secret his production processes and know-how, possibly justifying large parts of unrevealed production inventories, making the task of the notified body very uncomfortable. We therefore recommend that **the declarant shall prepare a file in which he assesses the influence of missing information on the carbon footprint result. Other ways are possible**, such as taking surrogates for specific products or putting anonymised product names for confidential data but still considering their flows in the process.

Complementary information

As many requirements are described in this regulation, we suggest setting up a number of illustrations by means of realistic examples, for instance on two kinds of batteries (NMC and LFP), with possibly quite different supply chains, primary vs secondary data, and different recycling patterns. The test cases could also include the way verification will be performed. This procedure is applied in many standards through indicative annexes; it will be appreciated by companies as a practical guideline.

CEA could help, under conditions to be defined, by proposing case studies or reviewing the JRC examples.

Annex I: Resource shuffling

The subject of resource shuffling arose from the Cap-and-Trade mechanism for California electricity imports. California feared to import and pay a high price for electricity which would be labelled as 'low carbon' without any effect on the mix of neighboring states, if these states had only kept the share of high carbon kWh for themselves. This is the main example where ex-post assessment can be made and the phenomenon is evaluated to **underestimate by a factor 2 the carbon content** of electricity imported by California in 2021 (250g/kWh instead of 540g/kWh)[12].

More recently, the same questions came back in the EU concerning the Carbon Border Adjustment Mechanism (CBAM). Here the risk is that a foreign country avoids CBAM taxes by assigning on paper its low carbon electricity to aluminum or steel sent to EU, while keeping the coal-based electricity for other purposes, and without any impact on the total carbon emissions from their electricity system.

A definition of resource shuffling is proposed by ERCST[13] : *Resource shuffling occurs when clean foreign production is re-routed toward export to the EU, and dirty foreign production is sold elsewhere, leaving foreign production patterns ultimately unchanged*.

Size of the problem

Resource shuffling is considered by EC to be an *unescapable fact* and that *incentives for resource shuffling exist for any emissions-related policy that includes traded goods (e.g., CBAM or product standards)* ***where the carbon intensity of imported or exported products does not rely on default values only, but on actual emissions***[14].

According to CRU, it could *potentially have a major impact on the overall effectiveness of a carbon border adjustment mechanism*[15].

According to DIW Berlin[16], resource shuffling could reduce by 80% the CBAM on aluminum and by 50% on steel. Even a perfect traceability scheme cannot prevent resource shuffling if the supply chains can adapt to the regulation.

Most concerned products

The most concerned product by far is the electricity, and electricity-intensive products (aluminum, steel) as identified by ECRST and EC. As a matter of fact, *shuffling in [the case of electricity] could simply be the assertion that the clean portion of a grid's generation mix was dedicated to the exporting producer*.

EC spots the main areas where resource shuffling is feared:

- Attribution of low-carbon electricity, low-carbon heat, biomass to imported materials.
- Attribution of GHG emissions of a production process to co-products to improve the reported carbon intensity of basic material production. This particular point can be dealt with using clear allocation rules.
- Attribution of shares of recycled material to imported or exported goods.

Solution

As resource shuffling is a way to circumvent carbon regulations that is inherently linked to the use of specific emission values, **the only solution is to enforce the use of generic national or regional consumption mixes**.

As this solution reduces the efficiency in promoting low carbon batteries, we only recommend its use for the products that are most subject to resource shuffling. These are products

- with large difference between low carbon and high carbon options
- for which switching between low carbon and high carbon options requires low effort (commodity materials)

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[12] Powerex, The Western EIM's Approach To Applying California's Cap and Trade Program To Imports Is Undermining The Program's Core Objectives, tables 5 and 6

[13] ERCST, Adressing Crabon Leakage in the EU

[14] EC, working document on the proposal for CBAM

[15] CRU, Assessing the drivers and scale of potential resource shuffling under a CBAM

[16] DIW Berlin, Carbon Pricing of Basic Materials : Incentives and Risks for the Value Chain and Consumers

- where only a small share of the product is directed to a market covered by the regulation

In practice, we recommend using generic mixes for electricity and for commodity materials. The list of commodity materials could include aluminum and steel and be updated by EU depending on the detection of resource shuffling in the value chains.

It will be possible to revert to specific data once similar regulations apply to a large majority of the countries' electricity or material markets.

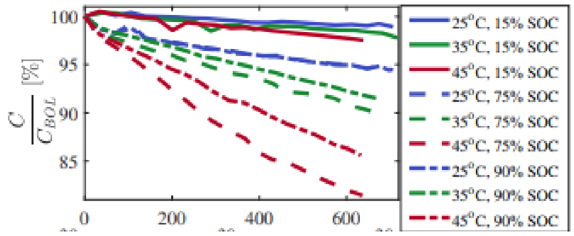
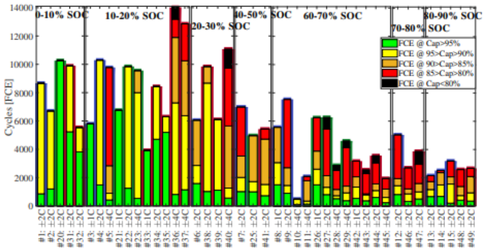
Annex II: Functional Unit shortcomings

The main shortcoming of the calculation of kWh delivered by the battery using GTR22 is the assumption that the battery is linked to a vehicle that is known at date of manufacturing, and which usage is known as well. It may be less and less the case.

For example, EP tender proposes tenders with included batteries that are used as range extenders for vehicles during their long trips. The same battery can be used to power a variety of vehicles, and also used to provide services to the electricity network while it is not in use for vehicles.
Battery swapping is experiencing a second breath: Nio performed 60 000 swaps in one day and installs 1000 swapping station in China this year. An interesting variation is module swapping (Ample, CATL, and seriously considered by some EU car manufacturers), where modules are added or removed from the car in a few minutes. The same module can power a large car or a small car, the same car can run with different number of modules depending on the forecasted trip. **The conversion between km and kWh at module level is completely impossible** in the case of module swapping.

Another bias is that the calculation proposed by JRC is based on cycle life, with the assumption that the vehicle will indeed perform the announced km, or the battery will indeed perform the cycles that have been demonstrated in the laboratory. It may not be the case. According to Geotab[17], *the vast majority of batteries will outlast the usable life of the vehicle*, and in fact *higher vehicle use does not necessarily equal higher battery degradation*. This is because batteries age not only with cycling, but also while doing nothing (calendar aging). A typical battery can perform ~2000 cycles, if the range is 300km it already amounts to 600 000 km, much more than many vehicles will ever do. And the battery may die long before due to calendar life.
This raises the problem of long-life announcements. The default value in GTR22 is 160 000 km. If a battery producer announces a 'million-mile battery' (10 times more) and can prove it via laboratory testing in reference conditions, should it be allowed to have a carbon footprint at production phase 10 time higher than other batteries? In practice many of the cars will end their life long before 1 million miles, and **the functional unit may present as clean a battery that will in fact be high carbon if it is less used than the manufacturer assumptions**.

The cycle life measured 'in reference conditions' chosen by the producer is highly dependent on the choice of these conditions, and often far from being predictive of real life: as the idea is to accelerate the ageing, the mechanisms can be different. For example, Wikner[18] shows at least a factor 10 between different conditions:

	 Figure 6.7: Cycling ageing in 10% DODs at different SOC levels and different C-rates at 25, 35 and 45°C.
Calendar life	Cycle life

Finally, with the proposed functional unit, if the vehicle in which the battery is installed is known at production time and also its lifetime (160 000 km by default), the resulting carbon footprint in CO2/kWh$_{\text{delivered}}$ will look

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[17] https://www.geotab.com/press-release/ev-battery-degradation-tool/

[18] https://research.chalmers.se/publication/512004/file/512004_Fulltext.pdf

like:
(Carbon at production and EOL) / 160 000 km / vehicle consumption
It is inversely proportional to vehicle consumption, which means that **larger, heavier, less optimized vehicles will result in better carbon footprints for the exact same battery**.

Annex III: System Boundaries

1. Infrastructure

In the PEFCR for the batteries, it is specified "*the infrastructure has been assessed based on the equipment requested to manufacture one unit of analysis of batteries*" but there are no recommendations as how to calculate it or what datasets to use. In order to check whether the infrastructure is really negligible, we performed a rough calculation of the impacts that could be generated by them.

To get an order of magnitude, we can look at the 'depreciation cost' or 'utility cost' in the cost structure. A literature review gave us estimates of the cost/kWh:

- Bloomberg 2018[19], 9\$/kWh$_{pack}$
- Avicenne 2022[20], 16 \$/kWh$_{cell}$
- Orangi & Stroman 2022[21], 20 \$/kWh$_{pack}$

Using a ~500g$_{CO2}$/\$ monetary emission factor, these emissions amount to around 10% of a battery pack carbon footprint.

Therefore, the **infrastructure emissions are not negligible in the total carbon footprint**.

2. Use phase

We present here a rough evaluation of the possible impacts of overconsumption due to a battery pack.

For example, with 10% losses and 50 Wh/km overconsumption due to 500 kg battery (80 kWh), over 160 000 km, additional electricity used is ~11 000 kWh, which may have higher footprint than the battery production itself in case the use phase electricity mix carbon content is high. Thus, **roundtrip losses and overconsumption of the car due to the presence of the battery should ideally be included**.

3. Charger: It is excluded because it is considered part of the infrastructure of the vehicle (PEFCR 2020), we agree with this assumption. We **recommend specifying that the inverter be excluded** too.

4. Junction box: It is **important to include the junction box**, which is part of the pack and contains aluminum, copper, integrated circuits, contactors…

5. Cooling system and coolant:

The JRC includes the cooling system and the coolant in the boundaries. This is not very clear. In many vehicles, the same system (same heat pump, same pumps, same pipes) is used to cool and/or heat the battery, the inverters, the chargers, the passenger compartment, an oil circuit... It is very dependent on the vehicle and could even be coupled in refrigerated trucks with the storing compartment.

We recommend **including only the heat transfer fluid that is contained in the battery pack, the eventual pipes inside the battery pack to distribute it and the plug used to connect to the heat management system of the vehicle**. Concerning the cooling system, the **pumps should be removed** of the examples as they are out of scope.

6. Transport:

JRC methodology includes the transport of raw materials and components in the 'raw materials acquisition and preprocessing phase. It is present in some but not all LCI tables. As noted in PEFCR, "*In general transportation has a negligible impact on the environment in the life* cycle of a rechargeable battery". Our literature review finds a range of 0.1%-3% of overall carbon footprint due to transport of the materials/products from different

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[19] https://www.beroeinc.com/article/lithium-ion-batteries-price-trend-cost-structure/

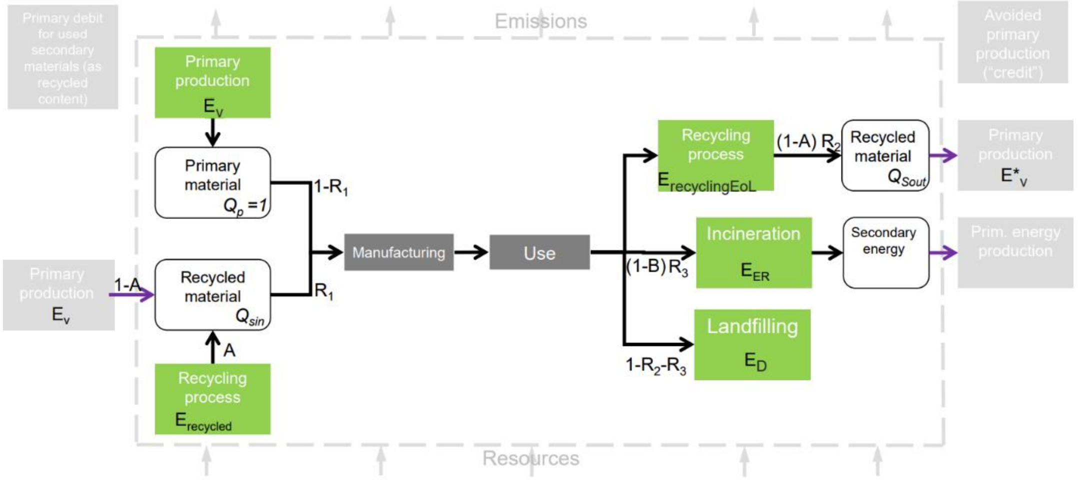
[20] C. Pillot, The Rechargeable Battery Market and Main Trends 2020-2030

[21] https://www.mdpi.com/2313-0105/8/8/83

sites of production.
A simple calculation for 1 kWh of battery (6kg) assuming upstream 21 kg (10 kg of concentrated metals [Ni, Co, Mn], 4kg of Li_2CO_3 or LiOH, 1 kg of graphite, 6 kg of other components) transported by boat over 18 000 km (14kg_{CO2}/tkm) and by truck over 1000 km (92 kg_{CO2}/tkm) according to EC recommendation 2021/2279 gives an upper limit of 7kg_{CO2}/kWh_{pack} for transportation of materials and products.
We recommend **including transport of inputs in all LCI tables**, but we do **not consider it necessary to make a distinct step for transportation** or make it mandatory to report separately the results linked to transportation.
'Final use site' (l.286) should be more precisely defined (car manufacturer factory? selling point to end user?)

Annex IV: End-of-Life and Recycling

JRC proposes to use the Circular Footprint Formula (CFF) with A=0.2



It is important to distinguish two different recycling processes:

- in input, a fraction R_1 of materials comes from recycling performed at the date of the battery production
- in output, a fraction R_2 of materials are recycled at the date of the battery end of life.

As recycling should not be double counted, parameter A tunes the weight given to recycling applied to input materials vs recycling at end of life. Here, JRC choice gives a high weight to recycling at end of life.

1. Limitations caused by A = 0.2
    a. Recycling process at end of life is largely undefined at time of battery production.

As battery lifetime will probably lie between 10 and 15 years, **the process applied at EoL (including, recycling) is prospective and cannot be foreseen at the time of production**. In particular, $E_{recyclingEoL}$, Qs_{out}/Q_p, and R_2 (including collection rate) are largely unknown. It will be nearly impossible for a battery manufacturer to justify that a process different from the default one (modelled in Annex 3 Table7) will be applied 15 years later. Therefore, this EoL recycling step will not be discriminant between producers. In fact, recycling is under active development and CEA considers processes and inventories significantly different from JRC default one (tables 7, 8, 9). On the contrary, at the time of battery production, the recycling process used for input recycled content is necessarily well defined.

    b. The proposed methodology cancels a large part of material extraction impacts by credits that happen much later and are not guaranteed.

With the proposed parameters A=0.2 and R_2=0.95 for many metals, **76% of raw material impacts are cancelled by recycling at end of life**. However, the material extraction impacts are occurring for sure at the time of production, but the EoL recycling will happen only if the processes are sufficiently developed and performant at that time, and if the battery is effectively collected and recycled[22].

Furthermore, it is largely debatable that 1kg CO2 avoided in 15 years from now cancels 1 kg CO2 produced today. In the meantime, this CO2 will have produced radiative forcing.

    c. The choice of A=0.2 is not necessary to incentivize end of life recycling

In the case of a value-chain where a material is recycled several times, a low value of A affects the impacts of material extraction to the last user of the chain. It incentivizes end of life recycling.

In the case of this battery regulation, specific requirements apply to end-of-life recycling (art. 57), so there is no further need to use CFF to promote end-of-life recycling. On the contrary, the recycled content used at production date is available data, and additional incentives to use a large recycled content is welcome.

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[22] In France, in 2022, 500,000 end-of-life vehicles are exported or illegally treated each year (https://www.vie-publique.fr/consultations/284321-projet-de-decret-gestion-des-vehicules-hors-dusage) for 1.4 million end-of-life vehicles treated in approved treatment centers.

2. R_2

In the JRC report (section 6.6.1 table 2), the default R_2 values are specified according to the requirements set by the battery regulation for recovery targets in 2031 (art.57). However, according to EC Recommendations 2021/2279, « *R_2 shall take into account the inefficiencies in the collection and recycling processes* ». Therefore, the value of 0.95 for Ni, Co, Mn and other metals seems too high. Indeed, this value implies a 100% collection rate, but this is far from being the case nowadays. We recommend including a more realistic collection rate in R_2.

What's more, in the requirements there is a recovery target for the lithium (80%) but it is not considered in the JRC report (R_2=0).

We recommend using the same collection rate for lithium as for other metals and the 80% recovery target.

3. $E_{recyclingEoL}$ factor

Firstly, there is currently no dataset relative to battery recycling in the LCDN. Without these secondary datasets, it is highly probable that Batteries CF may not be calculated by 2024, by several battery assemblers/producers. The LCDN shall be completed accordingly.

Yet, doing so, it should be kept in mind that secondary datasets for future batteries recycling (which processes are not yet upscaled) are by nature imprecise; the Data Quality Rating (DQR) shall properly reflect this. The latter, as per Tables 23 and 24 in the EC Recommendation of the 15th of December on the use of the Environmental Footprint methods, is not adapted to future/prospective processes. In particular the JRC shall adapt and clarify the criteria "Time representativeness" and "Technology representativeness", and their rating, in order to support DQR quantification for future EOL recycling processes.

4. $E_{recycled}$ factor

$E_{recycled}$ (E_{rec}) stands for the specific emissions and resources consumed (per functional unit) arising from the recycling process of the recycled (reused) material, including collection, sorting and transportation process. This term of the CFF is therefore "material-specific", whereas recycling processes to produce battery raw materials are classically multi-input (diverse types of waste treated; e.g., in the case of a waste battery recycling facility: batteries with diverse chemistries treated) and multi-output (diverse raw materials produced). Moreover, parts of the recycling processes are material- (including, metal-) specific, and shall be specifically allocated to these materials/metals. Thus, we recommend that the JRC **specifies the approach to solve this multi-functionality issue** associated with the term $E_{recycled}$ of the CFF, in a dedicated section of the report.

5. Quality of recycling

The quality of the outgoing secondary material, i.e., the quality of the recyclable material at the point of substitution, is not considered with sufficient level of details. The CF Rules state that "the quality ratio Q_{sout}/Q_p […] shall be taken from the general EC Recommendations 2021/2279 (Annex II - part C) unless evidence is provided for the use of diverging values". In this "Part C", default values of one (i.e., depicting a quality equivalent to that of primary materials) are in particular set for "steel", "aluminium" and "other metals". This implies the following issues:

- Default values for the quality ratio Q_{sout}/Q_p are not reported for a number of raw materials outgoing from battery recycling (e.g., lithium salts);
- Due to the values of one seemingly applicable as default to the raw materials recycled from waste batteries (as per the category "other metals"), the CF Rules fail to reward (and incentivize) high quality recycling, without any proper consideration of the actual quality (e.g., presence of impurities) of outgoing secondary material.

The recommended solutions to solve those issues are:

- Providing **a more extensive list of default values for quality ratios**, including for those materials potentially recycled from batteries. The default values shall be based on scientific and technical considerations – and set to 1 only if found relevant;
- Clarifying the terms "unless evidence is provided for the use of diverging values" by providing a **unique, standardized, approach for the calculation of company-specific quality ratios**.

The CF Rules shall accordingly appropriately reflect that “*quality depends on technical characteristics of the recyclate, which determine if it is adequate (thus functional) for a certain end application or not.*”[23]

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[23] Tonini et al., 2022

Annex V: Electricity modelling

The mean distance travelled on the transport network can be defined as the sum of the power on each km of line, divided by the total power produced and consumed.
It can be estimated from transport losses. Using the spreadsheet calculator from WECC[24], for 345kV lines, losses of 22%/1000km can be calculated. RTE announces overall 2.31% losses[25] in the French transport network, which implies that electricity travels on average 105 km. This figure of ~100 km has been confirmed orally by RTE, which added that it is progressively increasing with the share of variable renewables. The value of losses implies that the distance travelled will seldom exceed 1000 km with the current level of voltage.
Electricity is easy to transport over these distances, but very difficult to store at reasonable costs, except a small fraction in pumped hydro, and even far less in batteries. Therefore, electricity consumed at a given time can be produced elsewhere but at the exact same time (1h is the contractual timestep in electricity networks). The distance itself is limited by losses (1000 km seems a reasonable maximum) and by interconnection capacities.
The existing contractual instruments based on certificates (book and claim principle) are far from satisfying in this respect. Uniqueness of claim is perhaps a necessary condition but is far from sufficient. As explained in CEA answer to EC consultation on the Renewable Energy Directive[26]:

- The certificates lifetime shall not exceed 1h. Today and in JRC recommendations, the validity is one year (art.19 of Renewable Energy Directive). Thus, they act as a free long-term virtual storage system for the provider, the real costs of intermittence being transferred to the other consumer and/or the taxpayers.
- The exchange of certificates between countries shall be limited to the bookings of interconnections between these countries. Otherwise, GO certificates act as a free, lossless, high-capacity virtual line, the real costs being again transferred to the taxpayers.
- The certificates shall cover all types of electricity production and shall be associated with corresponding carbon content. Today, the information of electricity carbon content is highly incomplete for the consumer.
- Book and claim certificates do not ensure that the consumer has indeed paid for the electricity generated by the producer for which the certificate has been issued.
- Few if any outside the EU have such a contractual instrument, and it is not necessarily compatible with the EU one.

Therefore, **we consider that such kind of contractual instruments based on book and claim principle are prone to greenwashing and shall not be taken into account.**

In the longer term, other instruments may allow a higher degree of confidence, such as PPA contracts, however, under the following conditions:

- Seller and buyer identities are disclosed
- The quantity of electricity and the contract duration are disclosed
- Any type of electricity generator is allowed, as long as it is identified together with the associated carbon content
- A mechanism ensures that the electricity is consumed by the factory during the same 1h time step as it is produced by the generator (temporal consistency).
- The factory and the generator are located in the same bidding zone (geographical consistency)

Finally, **even if a perfect traceability method were found, electricity would still be particularly vulnerable to**

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[24] WECC, Capital Costs for Transmission and Substations, 2019
[25] RTE, bilan électrique 2020
[26] 2021-11-CEA-UE-directive-developpement-durable.pdf

resource shuffling:

- There is a large difference between the carbon intensity of high carbon and low carbon electricity (factor 10),
- It is very easy to switch from high carbon to low carbon (just purchase the right certificates or PPA without any physical change in the factory nor in the supply chain),
- Only a small fraction of any country electricity production will be dedicated to batteries subject to EU regulation, therefore it is very easy to direct the clean electricity towards this battery production and dirty electricity to other consumers not subject to similar regulation, without any effect on the total country emissions.

Therefore, **even these better contractual instruments shall be excluded from the calculation of electricity carbon content for the purpose of battery carbon footprint.**

Only when most of the countries' electricity market will be covered by similar regulations, these better contractual instruments could be considered for carbon footprint regulations. This could take, at best several decades.

Annex VI: Secondary datasets

This Annex supports the recommendations developed in the main document regarding Section "6.3 Hierarchy for the selection of secondary datasets" of the CF Rules, namely with i) providing elements of context, ii) describing issues of imprecisions/underestimations in standard LCI datasets regarding primary raw materials, and potential implication for current/future LCDN, iii) detailing the potential for regionalization of LCI datasets for primary raw materials, and iv) describing a few ongoing and upcoming standard and legislative initiatives, for which we recommend that the potential interlinks with the CFR are investigated.

Context

Inventory data is (one of) the most crucial "issue" in LCA, and in particular in the LCA of metals production (Beylot, 2021[27]). This issue in particular relates to the data representativeness (geographical, technological, temporal), level of disaggregation ("black box" issue), completeness and consistency.

Secondary datasets may be used in the CF calculations to model the following life cycle stages: Raw material acquisition and pre-processing, Distribution and End-of-Life. Section 6.3 of the CFR specifies the Hierarchy for the selection of secondary datasets. On top of this hierarchy, the selection of the secondary datasets to be used shall be done with prioritizing "EF-compliant dataset representative for the considered product/process registered on the Life Cycle Data Network (LCDN)". The CFR provide a link to the LCDN.

We acknowledge the tremendous effort of the JRC and of the EC i) to set the guidelines for what are considered "EF-compliant datasets", and ii) to compile the EF-database of products and processes as available on the LCDN. This database additionally builds on tremendous efforts from a number of stakeholders, including LCI databases suppliers and industrial associations.

However, as stated in the main document, we are concerned that incompleteness of the LCDN database (missing datasets) and some imprecisions/underestimations in standard LCI datasets may alter the quality in the results of the CF calculations, to an extent that is difficult to quantify at this stage but that is most probably significant.

Issues of imprecisions/underestimations in standard LCI datasets and potential implication for current/future LCDN

Recent scientific literature on the LCA of battery-grade graphite production showed that inventories, including in standard LCI databases, may have so far resulted in underestimated CF of battery-grade graphite production. In particular, the inventory as recently compiled by Surovtseva et al. (2022)[28] "suggests that GHG emissions and energy consumption for synthetic graphite may be more than double the values reported in prior work"; while Engels et al. (2022)[29] state that "often very outdated and not representative data from databases are used to conduct LCA of batteries […] with a large part of the production steps of graphite […] not taken into account". Moreover, in another recent study by Engels et al. (2022), the carbon footprint of natural graphite is calculated to be "more than four times higher than the value reported in ecoinvent version 3.7.1", due to "the energy-intensive coating step, which has been neglected or underestimated in many previous publications".

Similarly, in a recently published scientific article (Schenker et al., 2022)[30], environmental impacts (in particular, GHG emissions) of Li_2CO_3 production from brines were demonstrated to be underestimated in the literature.

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[27] Beylot, A. 2021. LCA of metals production: key challenges ahead and potential way forward. PROMETIA Life Cycle Analysis Webinar. 31st August 2021. https://prometia.eu/2021/09/21/prometia-held-a-webinar-on-lca-and-sustainability-on-31-august/

[28] Surovtseva, D, Crossin, E, Pell, R, Stamford, L. Toward a life cycle inventory for graphite production. J Ind Ecol. 2022; 26: 964– 979. https://doi.org/10.1111/jiec.13234

[29] Engels, P., Cerdas, F., Dettmer, T., Frey, C., Hentschel, J., Herrmann, C., Mirfabrikikar, T., Schueler, M., 2022. Life cycle assessment of natural graphite production for lithium-ion battery anodes based on industrial primary data. Journal of Cleaner Production 336, 130474. https://doi.org/10.1016/j.jclepro.2022.130474

[30] Schenker, V., Oberschelp, C., Pfister, S., 2022. Regionalized life cycle assessment of present and future lithium production for Li-ion batteries. Resources, Conservation and Recycling 187, 106611. https://doi.org/10.1016/j.resconrec.2022.106611

Authors state that “this mainly is a consequence of only assessing Li_2CO_3 production at Salar de Atacama and assuming that these data are representative of Li_2CO_3 production in general, which is not the case.” Underestimation of CF in the LCDN datasets for primary raw materials would imply the underestimation of the declared CF for the whole battery. We therefore state in the main document that “when completing the LCDN with additional datasets relative to primary raw materials production, the JRC shall ensure the highest level of quality possible […]”. This further implies that “the JRC shall pay particular attention to avoid underestimating CF of primary raw materials in the LCDN; which would subsequently disincentivize the use of primary data, failing to drive the market towards larger reliability of CF values, and any support actions towards reducing this footprint.”

Global datasets for metals production in standard LCI databases, whereas finer granularity improves quality of the CF assessment

In general, finer granularity in LCI datasets, e.g., in terms of technology and geography, improves quality of the CF assessment – quality as shall be captured by the DQR (in Section 6.4 Data quality requirements). This is in particular the case regarding the life cycle stage of “Raw materials acquisition and pre-processing”. Fiorletta et al. (2020)[31] proceeded to an in-depth review and investigation of existing LCI datasets (including e.g., assessment of representativeness) relative to metals (covering eight metals, including in particular lithium, cobalt or nickel), considering both ecoinvent and Gabi databases as well as the scientific literature. This review highlighted that significant discrepancies in carbon footprint values may be observed depending on the geographical and technological coverage considered in each LCI dataset.

As a first example, recent studies in the scientific literature demonstrated that “the source of lithium affects the amount of GHG emissions related to Li-ion battery production” (Schenker et al., 2022; Kelly et al., 2021)[32]. In particular “Impacts on climate change, […] from lithium carbonate production differ substantially among sites” (Schenker et al., 2022), while Kelly et al. (2021) observed key differences between the environmental impacts of brine- and ore-based lithium production, in a life cycle perspective. Moreover, as a second example, it is to be noted that a number of datasets representative for battery raw materials, as available in standard LCI databases (and/or provided by industrial associations), build on a share of the market only; yet with limited knowledge so far on the influence of this missing share. This is e.g., the case of LCI datasets associated with cobalt compounds, as compiled by the Cobalt Institute[33]. Inventory for Crude Cobalt Hydroxide covers 37% of the global production (Tri-Cobalt Tetraoxide: 8%; and Cobalt Sulphate Heptahydrate: 9%), in a context where regarding Tri-Cobalt Tetraoxide and Cobalt Sulphate Heptahydrate, “more than 70% of cobalt refining takes place in China, and no Chinese refiners were included in the study” (Cobalt Institute, 2023). Similarly, the inventory compiled by the Nickel Institute regarding nickel sulphate production is derived from 4 plants respectively in Belgium, Finland and Japan. Accordingly, it builds on 15% of the production in the World (Sphera, 2020)[34], while excluding several other productions (e.g., from Chinese plants).

Therefore, in the above main document we recommend that the completion of the LCDN (i.e., tackling the issue of incompleteness of the LCDN) shall be performed with assessing “the opportunity to provide regionalized datasets, at a level of granularity to be defined”. This will simultaneously support: i) accounting for the largest knowledge of some battery manufacturers/assemblers on their supply-chains; ii) incentivizing the use of primary data; and iii) overall enabling a larger quality of CF results, including adequate quantification of the quality of the calculated CF.

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[31] Fiorletta, M., Lai, F., Tomasetta, C., Bonnemaison, M., 2020. Impacts environnementaux des activités minières pour quelques matières premières. Rapport final.

[32] Kelly, J.C., Wang, M., Dai, Q., Winjobi, O., 2021. Energy, greenhouse gas, and water life cycle analysis of lithium carbonate and lithium hydroxide monohydrate from brine and ore resources and their use in lithium ion battery cathodes and lithium ion batteries. Resources, Conservation and Recycling 174, 105762. https://doi.org/10.1016/j.resconrec.2021.105762

[33] Cobalt Institute, https://www.cobaltinstitute.org/sustainability/life-cycle-assessment/ , accessed March 2023

[34] SPHERA, 2020. Life Cycle Assessment of Nickel Products. Reference year 2017. Final report. 25/05/2020

Potential interlinks with ongoing and upcoming standard and legislative initiatives

In the main document, we recommend that the JRC and the EC clarify potential interlinks with ongoing and upcoming standard and legislative initiatives, and in particular:

i) how the LCDN will be complemented, and potentially updated, through Environmental Footprint data compiled in the context of the “CRM Act” (proposal for a Regulation establishing a framework for ensuring a secure and sustainable supply of critical raw materials of the 16th of March 2023). Article 30 of the “CRM Act” proposal states that “The Commission may adopt calculation and verification rules for a specific critical raw material […] Any natural or legal person that places on the market critical raw materials for which the Commission has adopted [these] calculation and verification rules […] shall make available an environmental footprint declaration”.

ii) how the JRC CF Rules will interlink with standard systems for sustainable mining (potential alignment/misalignment). For example, one of the main certification standards, the IRMA system (IRMA, 2018)[35] covers the greenhouse gas emissions of mining sites with an objective to minimize climate change impacts through increased energy efficiency, reduced energy consumption and reduced emissions of greenhouse gases. Operating companies aligned with IRMA standard shall a) Disclose to IRMA auditors an accounting of greenhouse gas emissions from the mining project, achievement of and/or progress towards mine-site-level greenhouse gas reduction targets, and efforts taken to reduce emissions from the mining project and mining-related activities; and b) Publicly report on mine-site-level or corporate-level greenhouse gas emissions, progress towards greenhouse gas reduction targets and efforts taken to reduce emissions. The information is preferred at the mine site scale. The reporting of greenhouse emissions within the sustainable mining standard certification could be seen as an additional source of primary data related to extraction sites, and/or of secondary data if compiled in a secondary database.

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[35] IRMA standard, June 2018. https://responsiblemining.net/wp-content/uploads/2018/08/Chapter_4.5_GHG_Emissions.pdf

Annex VII: Data Quality Requirements

In the above main document, we provide two recommendations on section 6.4 Data quality requirements, respectively i) regarding the reporting (i.e., labelling) of the DQR in addition to the CF value, and ii) regarding a revision of section "6.4 Data quality requirements" on the approach for the calculation of the DQR.

In this Annex: i) we provide complements regarding the importance of reporting/labelling the DQR in addition to the CF, and ii) we detail our recommendation regarding improvement needs on the DQR.

On the importance of reporting/labelling the DQR in addition to the CF

In the JRC CFR, the data quality rating (DQR) shall be based on EC Recommendation 2021/2279 (Annex I, section 4.6.5). We consider that the CF of a battery as calculated from the CFR entails two types of information: i) the CF value per se, and ii) its associated quality. The term "quality" here refers to the quality of the data used in the calculations, which covers (here using the terms of the EC Recommendation on the use of the Environmental Footprint methods of the 15th of December 2021) "various aspects, such as technological, geographical and time-related representativeness, as well as completeness and precision of the inventory data". We recommend that the two key output pieces of information from the implementation of the CF Rules are explicitly reported (i.e., labelled, and not reported in the CFB supporting study): i) the CF value and/or class of value, and ii) the quality associated with the assessment (i.e., the DQR value associated with the calculated CF). From a scientific perspective, it is crucial that the CF is informed with its associated level of uncertainty. From the perspective of the CF Rules' implementation, it is crucial that the DQR is adequately used to drive the value chain towards a higher quality of results. Labelling the DQR value in addition to the CF will incentivize the use of data with higher quality (as reflected with lower DQR).

Improvement needs on the DQR

In the main document we state that:

"We recommend that, by a time horizon to be defined (e.g., 5 years), the JRC and the EC explicitly plan a revision of section 6.4 Data quality requirements. This revision shall in particular include:

- *increasing the level of requirements (i.e., of constraints) for those data referred to as of Good, Very Good and Excellent quality, both regarding company-specific datasets and secondary datasets."*

For example, regarding company-specific data (as per Table 23 in the EC Recommendation 2021/2279), when "The activity data and elementary flows partly reflect the geography where the modelling of the process in the newly created dataset takes place", the rating for Geographic representativeness is currently set to "2" (recalling that overall DQR of 2 is still considered of "Very good quality"). We recommend that, by 5 years, this rating is downscaled to 3 or 4.

Regarding secondary datasets (Table 24), when "The technologies used in the EF study are only partly included in the scope of the dataset", the rating for Technology representativeness is currently set to "3" (recalling that overall DQR of 3 is still considered of "Good quality"). We recommend that, by 5 years, this rating is downscaled to 4.

More generally, beyond this example, we recommend that the JRC and the EC consider increasing the values of DQR criteria (that is, translating lower quality) as per updates of Tables 23 and 24 of the EC Recommendation 2021/2279, for implementation in the CF Rules.

Moreover, in the main document, we state that:

"This revision shall in particular include […] creating sub-categories in order to better differentiate between levels of uncertainties."

For example, Table 23 of the EC Recommendation 2021/2279 states that when using company-specific information:

- A DQR of 1 shall be considered when "the elementary flows and the activity data explicitly depict the technology of the newly developed dataset",
- while a DQR of 2 shall be considered when "The elementary flows and the activity data are a proxy of the

newly developed dataset's technology."

Yet such discontinuous rating approach fails to capture the potential diversity in the quality of associated data; e.g., diverse on-site collected activity data may be all rated as 1 whereas of very diverse uncertainty (e.g., uncertainty of measurement; imprecision due to limited data; etc.); and similarly regarding e.g., diverse "proxies" leading to a common rating as 2. This shall be properly reflected in the updated section 6.4 Data quality requirements that we claim the JRC and EC shall consider by a medium term.

It is to be noted that this revision on the DQR - that we recommend being made - may be independent of any revision of the DQR general calculation approach as per the EC Recommendation 2021/2279. That is, only Section 6.4 Data quality requirements of the JRC CF Rules may be modified, with a specific DQR accounting approach.

Improved secondary datasets (as per our recommendations) and resulting improved DQR

Finally, linked to our recommendations (in the above main document) regarding secondary datasets relative to lithium carbonates and lithium hydroxides; battery-grade graphite, either natural or synthetical; cobalt compounds; nickel compounds; and battery precursors, which are absent from the current LCDN version: in case these datasets are planned to be integrated into the LCDN (in a time horizon to be defined), it is crucial that the DQR associated with these datasets properly reflect the level of quality of the associated data, in particular in terms of technology and geographic representativeness. The DQR assessment shall be made transparent. Regionalised datasets shall be provided with DQRs that properly reflect better geographic (and potentially technology) representativeness.

Annex VIII: Allocation Rules

This Annex specifically details two of the recommendations that are made in the main document regarding Section 6.7 Allocation rules.

1) In the main document, we state that “this implies in addition clarifying the sentence lines 478-480, which may leave room to diverse interpretations”. This refers to the following statement in the CFR: “*Economic allocation shall be applied only at the process step where the precious metal is extracted, as the economic value and mass output is very disparate compared to base metals, such as copper, nickel or cobalt*”. This shall be clarified, in particular building on the following questions:

- Does it imply that allocation shall not be performed regarding copper, nickel or cobalt?
- If yes, then how impacts associated with processes that simultaneously concern multi-metals (e.g., mining and concentration with production of respectively an ore and a concentrate containing several metals) shall be handled in that case?

2) Moreover, in the main document we state that: “*We recommend that this report on CF Rules additionally specifies allocation rules i) in the case of battery-grade lithium production from geothermal brines, and ii) in the case of graphite, whose co-products (and their potential for substitution on the market) are unclear so far in LCA practice*”

Regarding the case of battery-grade lithium production from geothermal brines, it is to be noted that the French-German border is an important reservoir for such brines, which are currently being exploited for power and heat generation and appear promising for industrial production in the next decade, as e.g. demonstrated by the EIT co-funded EUGELI project[36]. Some industrials in the field have recently claimed for zero and even negative greenhouse gas emissions, based on LCA[37]. Moreover, in the case of graphite production, co-products (and their potential for substitution on the market) are unclear so far in LCA practice (Surovtseva et al., 2022).

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[36] https://www.brgm.fr/en/current-project/eugeli-lithium-extraction-geothermal-brines-europe

[37] see e.g. https://www.investi.com.au/api/announcements/vul/722befd4-0d1.pdf

Annex IX: Potential of geochemical traceability to support verification

In the main document we recommend i) that “the JRC amends section 7.3 to mention the potential of geochemical traceability techniques to verify and validate the data used to calculate the CF […]” and ii) “an update of the CF Rules regarding the potential use of these geochemical traceability techniques, in a time horizon to be defined (e.g., 5 years). […]”
In this Annex, we provide complementary elements regarding i) geochemical traceability, and ii) current developments in particular funded through a Horizon Europe project, for potential consideration by the JRC for any future update of the JRC CFR (at a time horizon to be defined).

The concept of “traceability” is mentioned only once in the CFR, regarding traceability of recycled materials: “When using a company specific R1 values other than 0, traceability throughout the supply chain is necessary”. In particular chemical traceability is not clearly mentioned in the CFR, while it could be used to verify and validate the origin of raw materials throughout supply chains and up to the battery. This may be particularly relevant in view of using regionalized LCI datasets for the modelling of the CF of raw materials acquisition, which appears particularly crucial as mentioned in our above recommendations (e.g., regarding lithium originating from different regions, with different footprints).
Fingerprinting approaches using chemical traceability have been developed to certify and validate the origin of numerous natural commodities (food, wood, agro, petrol, cultural materials, gemstones, etc.). Material Fingerprinting (MFP) uses intrinsic information contained in the material itself. Mineral resources (ores) originate from an immense variety of deposits, highly differentiated in terms of geological genesis and age. These result in specific mineralogical, geochemical, optical, textural properties (fingerprints) of ores that can be used to discriminate the raw materials sources in terms of deposit type or geographical origin at various scales (country, region, district, individual mines).
The MFP principles have been developed by BGR (Bundesanstalt für Geowissenschaften und Rohstoffe) to trace the origin of columbite-tantalite (“coltan”). For lithium, the MFP method using the isotopic signature was tested by BRGM[38] throughout the supply chains up to the final product (i.e., the battery). The study showed that the isotopic analysis of lithium in batteries allowed to distinguish in most cases whether the lithium used came from salar or from a hard rock deposit. The European project MADITRACE “Material and digital traceability for the certification of critical raw materials” (2023-2025, grant number101091502) led by BRGM and in collaboration with CEA will develop and test independent analytical methodologies for critical raw materials (CRM) traceability (in particular lithium, cobalt and natural graphite in battery). The goal is to integrate them into a generic certification scheme for responsible and sustainable CRMs throughout mineral supply chains from the mine to the manufactured and recycled products.

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[38] Desaulty, A.M., Monfort Climent, D., Lefebvre, G., Cristiano-Tassi, A., Peralta, D., Perret, S., Urban, A., Guerrot, C., 2022. Tracing the origin of lithium in Li-ion batteries using lithium isotopes. Nat. Commun. 13, 1–10. https://doi.org/10.1038/s41467-022-31850-y