ZincFive

Comparative Review of Product Environmental Profiles: Nickel-Zinc vs. Lithium-Ion for Backup Power in UPS Applications

BC 2 UPS Battery Cabinet & Galaxy Lithium-ion Battery Cabinet

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Executive Summary

This study presents a systematic comparison of environmental impact indicators and inventory flows indicators from two published, third-party verified Product Environmental Profiles (PEPs):

1. BC 2 UPS Battery Cabinet (*Z5BC-00101-V01.01-EN* | verified by VH42)[1]
2. Galaxy Lithium-ion Battery Cabinet (*SCHN-01206-V01.01-EN* | verified by VH08)

The methodology of comparison for the two PEPs is as delineated below *(Section 2)*:

I. Registered with the PEP Ecopassport® program
   - *The two PEPs compared in this study are registered with the PEP Ecopassport®*

II. Drafted as per the same Product Category Rules *(Section 2.1)*
   - *The two PEPs compared in this study are governed by the drafting rules as per Product Category Rules for Electrical, Electronic and HVAC-R Products (PCR-ed4-EN-2021 09 06)*

III. Supplemented by the same Product-Specific Rules *(Section 2.2)*
   - *The two PEPs compared in this study are supplemented by the specific rules for Electrical switchgear and control gear solutions (PSR-0005).*

IV. Comparable functional units *(Section 2.1.1.2)*
   - *To enable valid comparison of indicators across both PEPs, this study normalizes the BC 2 functional unit from power rating (kW for a defined duration in minutes) to backup power capacity (kWh), consistent with the Galaxy Li-ion functional unit definition, while retaining the same reference service life in accordance with PSR Section 3.15.1.2.*

V. For product family declarations, same extrapolation rules *(Section 2.1.1.3)*
   - *As the extrapolation rules (PCR Section 1.1, Section 2.6) are defined by the declarant, sufficient information regarding the extrapolation rules for Galaxy Li-ion are not available for valid comparison.*
   - *Therefore, this study limits itself to the indicators declared for the reference product for both PEPs.*
   - *The 38-module configuration (ZF-38A6BS022KB1UF000) is the reference product for the BC 2 and the 17-module UL configuration (LIBSESMG17UL) is the reference product for the Galaxy Li-ion.*

VI. Life Cycle Impact Assessment (LCIA) method for Environmental impact indicators *(Section 2.5)*
   - *The BC 2 applies the EF 3.1 LCIA method, and the Galaxy Li-ion applies the EF 3.0 LCIA method.*
   - *Both studies were conducted in compliance with ISO 14040/14044 and EN 15804+A2, and both apply the Environmental Footprint (EF) LCIA framework published by the European Commission Joint Research Centre.*
   - *Therefore, to enable methodologically consistent comparison, this study applies a characterization factor adjustment to the BC 2 environmental impacts to derive EF 3.0 comparable environmental impacts, using average and median factors reported in Joint Research Centre (JRC) Technical Report EUR 31414 EN, "Updated Characterisation and Normalisation Factors for the Environmental Footprint 3.1 Method," published by the Publications Office of the European Union (Andreasi Bassi et al., 2023, JRC130796)*

The key findings from the comparison are as stated below. For results on all compared indicators for functional unit basis and kWh basis across all stages refer to *Section 3*, *Table 22* and *Table 23*.

1. Climate Change
   a. For this indicator, a lower value represents lower global warming potential.

[1] This study uses the terms 'BC 2' and 'Galaxy Li-ion' to refer to Z5BC-00101-V01.01-EN and SCHN-01206-V01.01-EN respectively.

b. On a per-kWh basis, BC 2 has a Climate Change impact (Total excluding Module D) of 255.9 to 257.7 kg CO_2 eq./kWh, compared to 383.3 kg CO_2 eq./kWh for Galaxy Li-ion, a difference of 32.8% to 33.2%. BC 2 is 0.7x Galaxy Li-ion.
c. At the manufacturing stage (A1-A3), BC 2 has a Climate Change impact of 193.3 to 194.7 kg CO_2 eq./kWh compared to 314.1 kg CO_2 eq./kWh for Galaxy Li-ion, a difference of 38.0% to 38.4%.
d. The manufacturing stage accounts for the largest share of each product's total Climate Change impact.

2. Acidification
    a. For this indicator, a lower value represents lower acidification potential.
    b. On a per-kWh basis, Galaxy Li-ion has an Acidification total (Total excluding Module D) of 2.34 Mole H+ eq./kWh, compared to 5.37 Mole H+ eq./kWh for BC 2, a difference of 56.5%. Galaxy Li-ion is 0.4x BC 2.
    c. At the manufacturing stage (A1-A3), the difference is 59.8%.
    d. At Module D, BC 2 has a credit of 2.98 Mole H+ eq./kWh compared to 0.18 Mole H+ eq./kWh for Galaxy Li-ion. Acidification is the only environmental impact indicator where Galaxy Li-ion has a lower total (excluding Module D) on a per-kWh basis.
3. Use of non-renewable primary energy (PENRE), Non-renewable primary energy resources used as raw materials (PENRM), and Total use of non-renewable primary energy resources (PENRT)
    a. For these indicators, a lower value represents lower use of non-renewable primary energy resources.
    b. On a per-kWh basis, BC 2 has a PENRE (Total excluding Module D) of 3,457 MJ/kWh compared to 5,389 MJ/kWh for Galaxy Li-ion, a difference of 35.8% (BC 2 is 0.6x Galaxy Li-ion).
    c. PENRT follows a similar pattern, with BC 2 (Total excluding Module D) at 3,564 MJ/kWh compared to 5,447 MJ/kWh for Galaxy Li-ion, a difference of 34.6% (BC 2 is 0.7x Galaxy Li-ion).
    d. PENRM shows the reverse pattern; Galaxy Li-ion uses 64.6 MJ/kWh compared to 94.1 MJ/kWh for BC 2, a difference of 31.4% (Galaxy Li-ion is 0.7x BC 2).
    e. At Module D, BC 2 has PENRE and PENRT credits that are 1.5 times larger in absolute value than those of Galaxy Li-ion on a per-kWh basis.
4. Use of renewable primary energy (PERE), Primary energy resources used as raw materials (PERM), and Total use of renewable primary energy resources (PERT)
    a. For these indicators, a higher value represents greater use of renewable primary energy resources.
    b. On a per-kWh basis, BC 2 has PERE (Total excluding Module D) of 1,199 MJ/kWh compared to 205 MJ/kWh for Galaxy Li-ion (BC 2 is 5.9x Galaxy Li-ion), a difference of 485.4%.
    c. PERT follows a similar pattern, with BC 2 (Total excluding Module D) at 1,205 MJ/kWh compared to 230 MJ/kWh for Galaxy Li-ion (BC 2 is 5.2x Galaxy Li-ion), a difference of 423.9%.
    d. PERM shows the reverse pattern: Galaxy Li-ion uses 25.0 MJ/kWh compared to 4.1 MJ/kWh for BC 2 (Galaxy Li-ion is 6.1x BC 2), a difference of 505.4%.
    e. The PERE and PERT differences are consistent across life cycle stages, with BC 2 having values 4.5 to 5.3 times those of Galaxy Li-ion at A1-A3 and up to 23 times at Module D.
5. Use of net fresh water (FW)
    a. For this indicator, a lower value represents lower net fresh water use.
    b. On a per-kWh basis, BC 2 has a FW (Total excluding Module D) of 2.2 m^3/kWh compared to 96.8 m^3/kWh for Galaxy Li-ion, a difference of 97.7% (BC 2 is 0.02x Galaxy Li-ion).
    c. At the manufacturing stage (A1-A3), BC 2 uses 1.8 m^3/kWh compared to 96.5 m^3/kWh for Galaxy Li-ion, a difference of 98.2%.
6. Materials for recycling (MFR)
    a. For this indicator, a higher value represents a greater output flow of materials leaving the product system boundary that are destined for reuse or recycling.
    b. On a per-kWh basis, BC 2 has an MFR (Total excluding Module D) of 16.2 kg/kWh compared to 6.5 kg/kWh for Galaxy Li-ion (BC 2 is 2.5x Galaxy Li-ion), a difference of 148.0%. This difference is split between the manufacturing stage (A1-A3), where BC 2 is 2.6 times Galaxy Li-ion, and the end-of-life stage (C1-C4), where BC 2 is 2.5 times Galaxy Li-ion. Neither product has MFR at Module D.
7. Hazardous waste disposed (HWD)
    a. For this indicator, a lower value represents less hazardous waste sent to disposal.

b. On a per-kWh basis, BC 2 has an HWD (Total excluding Module D) of 2.79 x 10^{-4} kg/kWh compared to 3,833 kg/kWh for Galaxy Li-ion. HWD differs by several orders of magnitude between the two products.
c. At Module D, the relationship reverses; Galaxy Li-ion has an HWD credit of 530 kg/kWh compared to 1.86 x 10^{-7} kg/kWh for BC 2.

8. Input of secondary material (SM), Materials for energy recovery (MER), and Exported energy (EE)
    a. For these indicators, higher values represent greater use of secondary materials, greater output flow of materials leaving the product system for energy recovery, and greater energy export, respectively.
    b. Galaxy Li-ion has non-zero values for SM (4.12 x 10^{-5} kg per functional unit), MER (1.26 x 10^{-7} kg per functional unit), and EE (5.59 MJ per functional unit) at the total life cycle level, while BC 2 has zero for all three indicators across all life cycle stages. Galaxy Li-ion is favorable in these categories. The percentage difference cannot be computed because the BC 2 values are zero.
9. Trends in LCA stages
    a. Environmental impact indicators
        i. For Total excluding Module D, BC 2 has lower impact in 9 of 10 environmental impact indicators on a per-kWh basis, with Acidification being the exception.
        ii. At the manufacturing stage (A1-A3), BC 2 has lower impact in 9 of 10 environmental impact indicators, again with Acidification being the exception.
        iii. At the distribution stage (A4), Galaxy Li-ion has lower impact in all computable environmental impact indicators (6 of 10; the remaining 4 are undefined due to Galaxy Li-ion 0* declarations).
        iv. At the installation stage (A5), Galaxy Li-ion has lower impact in 5 of 6 computable indicators.
    b. Inventory flows indicators
        i. For Total excluding Module D, BC 2 is favorable in 8 of 11 computable inventory flows indicators on a per-kWh basis.
        ii. Galaxy Li-ion is favorable in PENRM, PERM, and RWD. SM, MER, and EE are excluded from percentage difference calculations as BC 2 has zero across all stages; Galaxy Li-ion is favorable in all three.
        iii. At the manufacturing stage (A1-A3), BC 2 is favorable in 10 of 11 computable indicators, with PENRM being the exception. At A4 and A5, many inventory flows indicators are undefined due to Galaxy Li-ion 0* declarations; among the computable indicators, the results are mixed.
    c. Geographic and energy model context
        i. The A4 and A5 stage-level differences should be interpreted in the context of the differing geographic scopes stated in each PEP: BC 2 has distribution from the United States to Europe, while Galaxy Li-ion has United States-based distribution. The energy models also differ, with BC 2 applying a European energy model and Galaxy Li-ion applying a United States energy model at the installation and use stages.
        ii. Additionally, the two PEPs were modeled using different LCA software and background LCI databases (LCA FE v.10.9 with MLC 2024.2 for BC 2; EIME v6.1 with EIME 2023-02 for Galaxy Li-ion), which may contribute to differences in regionalized process data and waste classification across all stages.

1 Purpose of the study

A Product Environmental Profile (PEP) is classified as an Environmental Product Declaration (EPD), developed, independently verified, and registered under the PEP Ecopassport® program. EPDs are established under ISO 14025:2006.

An EPD provides transparent, multi-criteria, and verified quantitative data on a product's environmental performance across its entire life cycle[2]. A life cycle assessment (LCA), conducted in accordance with ISO 14040/14044 standards, is used in the development of EPDs. In addition to these standards, an LCA for an EPD is governed by drafting rules specific to the defined category of products, known as Product Category Rules (PCR), and further supplemented at the product subcategory level by Product Specific Rules (PSR).

European Standard EN 50693 specifies requirements for conducting an LCA in the context of environmental declarations for electronic and electrical products and systems. It defines rules for PCR development and provides guidance on how to develop corresponding PSRs in Technical Committees. The PEP Ecopassport® program builds on EN 50693 to establish PCRs for electrical, electronic, and HVAC-R products. A PEP is therefore an EPD developed specifically for this equipment category, verified by an accredited independent third party, valid for five years, and recognized internationally as a reliable instrument for product comparison, ecodesign decision-making, and international market reporting.

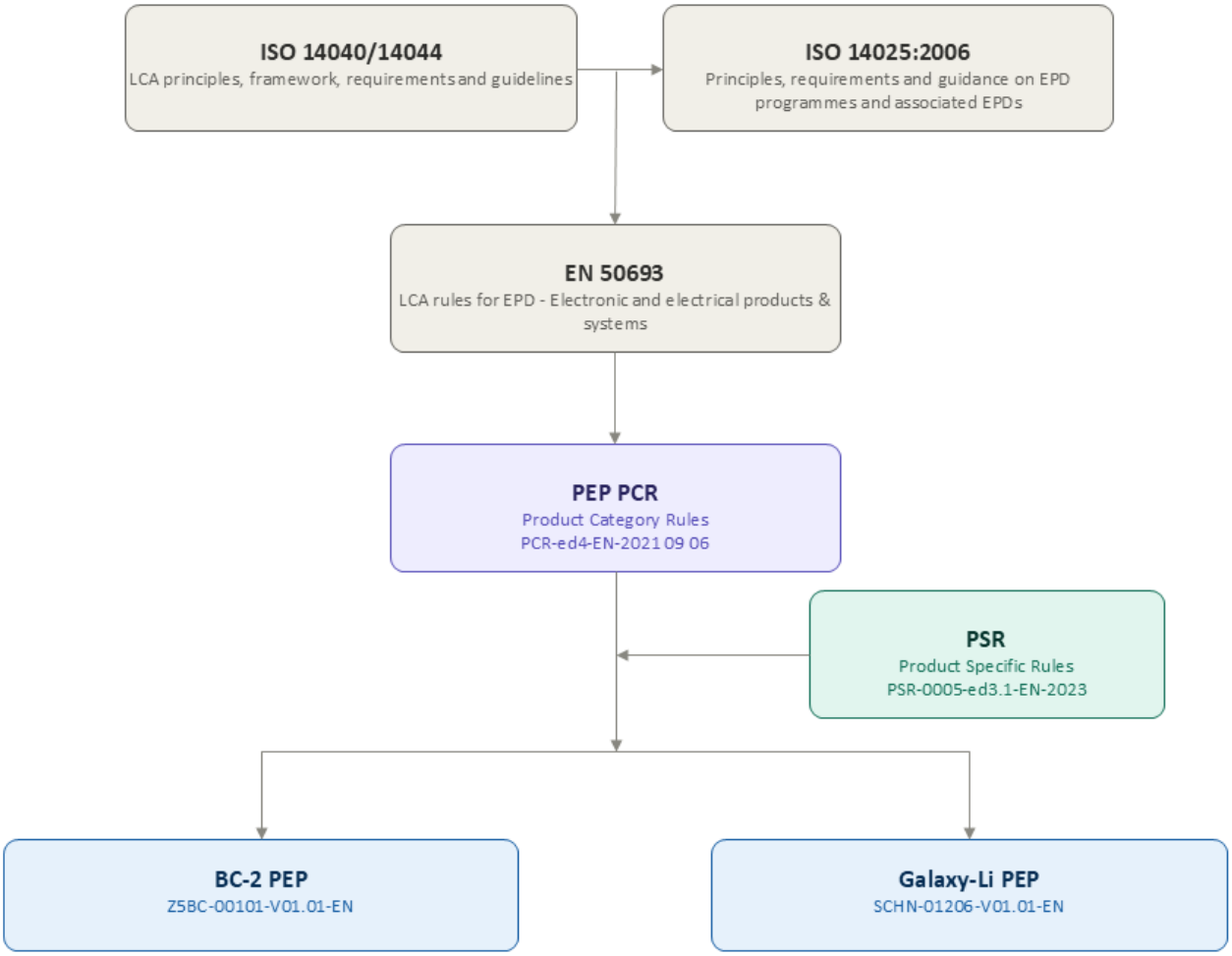


Figure 1 Hierarchy of standards, frameworks, guidelines and governing rules for PEPs.

[2] Life cycle is determined by the system boundary as specified in the relevant PCR.

The purpose of this study is to present a systematic comparison of environmental impact indicators and inventory flows indicators from two published, third-party verified Product Environmental Profiles (PEPs), both governed by (i) Product Category Rules (PCR) for Electrical, Electronic and HVAC-R Products (*PCR-ed4-EN-2021 09 06*) and (ii) Product Specific Rules (PSR) for Electrical Switchgear and Control Gear Solutions, Specific Rules for the 'Other Equipment' family (*PSR-0005-ed3.1-EN-2023*).

1. BC 2 UPS Battery Cabinet: *Z5BC-00101-V01.01-EN* and verified by VH42
2. Galaxy Lithium-ion Battery Cabinet: *SCHN-01206-V01.01-EN** and verified by VH08

This study was conducted by ZincFive LLC, manufacturer of the BC 2 UPS Battery Cabinet. Readers are encouraged to independently access both source PEP documents through the PEP Ecopassport® registry (www.pep-ecopassport.org) and verify all findings against those documents.

2 Methodology of comparison and limitations

This section describes the governing rules, normalization approach, and limitations that underpin the comparison presented in this study.

2.1 Product category rules

Product Category Rules (PCRs) are standardized sets of rules, requirements, and guidelines that govern how a Life Cycle Assessment (LCA) must be conducted and how its results must be reported for a defined category of products. Under ISO 14025:2006, PCRs are a foundational requirement, ensuring that EPDs within the same product category are developed using consistent system boundaries, functional units, impact assessment methodologies, and data quality criteria, thereby enabling meaningful and credible comparisons between products.

The PEP Ecopassport® PCR applies to electrical, electronic, and HVAC-R products. The PCR establishes drafting rules across three broad categories *(PCR Section 1.2)*:

I. Common rules for conducting Life Cycle Assessments: This segment describes the common LCA rules for all the categories of products covered by the PEP Ecopassport® program. It also specifies the requirements regarding data selection and quality.
II. Description of the contents of LCA report: This segment specifies the data information that must be included to ensure successful completion of the LCA report and draft the PEP.
III. Editorial rules for drafting a Product Environmental Profile:
This segment describes the editorial guidelines for creating PEPs, namely the sections to be completed and the information to be provided.

The PCR is supplemented, if necessary, by additional Product-Specific Rules (PSR) defined for each product category that specify the functional units and additional information in relation to the common rules (e.g. use scenario). PSRs are discussed in *Section 2.2.*



Figure 2 Composition of PCR (common rules + PSRs) in the PEP Ecopassport®.

The two PEPs compared in this study are governed by the drafting rules as per Product Category Rules for Electrical, Electronic and HVAC-R Products (*PCR-ed4-EN-2021 09 06*).

2.1.1 Functional unit, reference flow and reference product

2.1.1.1 Functional unit and declared unit

The indicators of a product or a system declared in a PEP are reported using two units, each addressing different needs:

I. Functional unit
II. Declared unit

The functional unit quantifies the performance of the service delivered by a product to the user. The main purpose of the functional unit is to provide a reference to which inputs and outputs are related in the LCA. The functional unit includes *(PCR Section 2.1)*:

I. The identification of the product function(s) under study. The function(s) describe the service delivered to the user.
II. The performance or requirement level achieved by the function(s). This level is quantified and may be determined according to the standards applicable to the product.
III. The reference service life (RSL).

The declared unit can be used, in addition to the functional unit, to provide complementary information. It is used as a reference unit in an environmental declaration when a functional unit cannot be used directly. Therefore, the declared unit enhances the scalability of the product's environmental impact indicators at a product or system level. When it is used, it must clearly specify *(PCR Section 2.1)*:

I. The quantity of product
II. The unit of measure
III. The mathematical relation between functional unit and declared unit, and if applicable, the reference service life

For the two PEPs in this study, the PSR (*PSR Section 3.15.3.1*) states that the environmental impact results generated by the life cycle of the reference product, with respect to the functional unit, are equivalent to the environmental impacts with respect to the declared unit. Furthermore, the Galaxy Li-ion reports environmental impacts only based on a functional unit and does not report a declared unit. **All comparisons in this study are therefore based on the functional unit**.

2.1.1.2 Functional unit normalization

The two PEPs compared in this study define their functional units in accordance with the PCR. However, the performance level, and therefore the functional unit basis, differs substantively between the two declarations, as illustrated in *Table 1***.**

Table 1 Published functional unit of BC 2 and Galaxy Li-ion.

PEP	Functional Unit	Note
BC 2	To provide 266 kW for five (5) minutes for a reference lifetime of ten (10) years for use in UPS applications.	The BC 2 defines performance in terms of power rating (kW), whereas the Galaxy Li-ion defines performance in terms of backup power capacity (kWh).
Galaxy Li-ion	To provide 34.7 kWh of backup power to 3-Phase and other compatible UPS models for 10 years.	

To enable valid comparison of indicators across both PEPs, this study normalizes the BC 2 functional unit from power rating (kW for a defined duration in minutes) to backup power capacity (kWh), consistent with the Galaxy Li-ion functional unit, while retaining the same reference service life in accordance with *PSR Section 3.15.1.2*. The normalization method is explained in the Annex. The normalized functional unit for BC 2 is presented in *Table 2.*

Table 2 Normalized functional unit of BC 2 and Galaxy Li-ion.

PEP	Functional Unit
BC 2	To provide **37.6 kWh of backup power** to 3-Phase and other compatible UPS models for **10 years.**
Galaxy Li-ion	To provide **34.7 kWh** of **backup power** to 3-Phase and other compatible UPS models for **10 years.**

Note: The impact for the BC 2 under the normalized functional unit "to provide 37.6 kWh of backup power to 3-phase and other compatible UPS models for 10 years" are identical to those published under the declared functional unit "to provide 266 kW for five (5) minutes for a reference lifetime of ten (10) years for use in UPS applications". The reference flow is unchanged between the two functional unit definitions; consequently, the values for environmental impact indicators and inventory flows indicators remain identical.

2.1.1.3 Reference flow and reference product

A reference flow is the measure of the process outputs in a given product system necessary to fulfil the function expressed by the functional unit (*PCR Appendix D*). The definition of the reference flow to fulfil the functional unit includes (*PCR Section 2.1*):

- The quantitative amount of product(s) used to fulfil the functional unit. These are known as the "**reference product**"
- The materials not found in the reference product, including waste and discarded materials, which are generated at each stage of the life cycle (manufacturing process, cutting, installation, etc.)
- All the packaging used during the reference service life
- Elements, flows, and processes required to distribute, install, use (maintenance, repairs, replacements, etc.), remove, dismantle, and process the reference product

Both PEPs in this study are product family declarations, i.e. a declaration performed for several commercial references belonging to the same product family from a single manufacturer. *(PCR Section 1.1)*
The PEPs cover products other than the reference product as they belong to the same homogeneous environmental family as the reference product. This is on the basis that all products have the same functionality, same product standards, similar manufacturing technology including same type of materials and manufacturing processes. Extrapolation rules are used for the group of products when the environmental data (i.e., material balance or environmental impacts) differ from those of the reference product. These rules allow the data to be estimated at every stage of the life cycle. *(PCR Section 2.6)*
The PCR further states that the extrapolation rules may be defined in the specific rules (PSR), in which case they can be directly applied. In the context of our study, the PSR does not define rules for extrapolation. Thus, the following rules are applied in accordance with the PCR.

"If no rules are set in the PSRs, the following stages shall be followed to define extrapolation rule(s):

I. Analyze the products covered by the PEP belonging to the same homogenous family
II. Perform the LCA of representative products (reference product) of the homogeneous family
III. Identify and quantify the product parameters that vary between the various products of the homogeneous environmental family (i.e. dimensions, weight of parts, materials, energy consumption, etc.) and conduct a sensitivity analysis to identify influential parameters.
The sensitivity analysis conducted to identify the influential parameters (e.g. product mass, power range, transportation distance etc.) should be undertaken for the potential highest and lowest environmental footprint products from the homogenous family (estimated from LCA of the representative product), together with a median product (if different than the representative product of the homogenous family)."
(PCR Section 2.6)

The extrapolation rules are defined by the declarant, however, sufficient information regarding the extrapolation rules for Galaxy Li-ion is not available for valid comparison. **Therefore, this study limits itself to the environmental impacts declared for the reference product for both PEPs.** The 38-module configuration *(ZF-38A6BS022KB1UF000)* is the reference product for the BC 2 and the 17-module UL configuration *(LIBSESMG17UL)* is the reference product for the Galaxy Li-ion. The range of products, weight, and dimensions of products for BC 2 and Galaxy Li-ion are mentioned in the *Table 3*.

Table 3 Range of products for BC 2 and Galaxy Li-ion.

PEP	Model Number	Battery Modules	Weight (kg)		Dimension (W x L x H) (m)		
			w/o Packaging	w Packaging	W	L	H
BC 2	ZF-36A6BS022KB1UF000	36	843.3	903.8	0.5	0.9	2.1
	ZF-37A6BS022KB1UF000	37	858.5	919.1			
	ZF-38A6BS022KB1UF000	38	873.8	934.3			
	ZF-39A6BS022KB1UF000	39	889	949.5			
Galaxy Li-ion	LIBSESMG10UL	10	355	401	0.587	0.65	1.97
	LIBSESMG13UL	13	415	461			
	LIBSESMG16UL	16	470	516			
	LIBSESMG17UL	17	490	536			
	LIBSESMG10IEC	10	355	401			
	LIBSESMG13IEC	13	415	461			
	LIBSESMG16IEC	16	470	516			
	LIBSESMG17IEC	17	490	536			

Note: The manufacturer selects the reference product within its range to be analyzed. The PSR sets no requirements.

2.1.2 System boundary

The system boundary is a set of criteria specifying which unit processes are part of a product system. The PCR states that environmental information included in the PEP shall cover all the stages of the life cycle ("cradle to grave"). The system boundary for both PEPs in accordance with the PCR is illustrated in *Figure 3.*

PEP ecopassport®	Manufacturing stage			Distribution stage	Installation stage	Use stage							End of life cycle stage				Benefits and loads)
	Production stage			Construction stage		Use stage							End of life cycle stage				Benefits and loads
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
EN 15978 / 15804	Procurement of raw materials	Transport	Manufacture	Transport	Installation processes	Use	Maintenance	Repair	Replacement	Restoration	Energy consumption during building use	Water consumption during building use	Demolition / Deconstruction	Transport	Waste treatment	Disposal	Benefits beyond the system boundaries

Figure 3 Module categories according to EN 15804:2012 +A2:2019. (PSR Section 4.3)

2.2 Product specific rules

In accordance with the General Instructions of the PEP Ecopassport® program and in addition to the PCR of the PEP Ecopassport® environmental product declaration program, the PSR (*PSR-0005-ed3.1-EN-2023*)[3] referenced in this study sets out the additional requirements applicable to Electrical Switchgear and Control gear Solutions. Both PEPs declare their product category as 'Other equipment, active product', which falls under *PSR Section 2.1.13* and is governed by the specific rules in *PSR Section 3.15*. The PSR defines specifications to be adopted by manufacturers in the development of their PEPs, particularly with regards to:

- The technology and its type of application
- The reference service life time
- The use scenarios adopted during the product use stage

2.2.1 Reference service life

In accordance with the PSR *(PSR Section 3.15.1.2)*, the reference service life for the reference product in both PEPs is 10 years for active products.

2.2.2 Default scenarios – use stage

In accordance with the PSR *(PSR Section 3.15.2.1)*, the use stage of both PEPs includes energy consumption. This is done by considering consumed power for each operating mode identified (OFF, standby, ON, etc.) and the duration of the operating modes expressed as a percentage of the full cycle time.

2.3 Life Cycle Inventory (LCI)

Life Cycle Inventory (LCI) is defined as the "phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle" (*ISO 14044:2006, paragraph 3.3*).

[3] Both PEPs reference PSR-0005. BC 2 cites the more recent PSR-0005-ed3.1-EN-2023 12 08, while Galaxy Li-ion cites PSR-0005-ed3-EN-2023 06 06. Edition 3.1 is a minor revision to edition 3, and the specific rules governing the "Other equipment" product family (section 3.15) remain consistent between the two editions, preserving comparability.

The LCI phase accounts for all material and energy flows entering and leaving the product system, including inputs from nature (raw materials, energy resources, water) and outputs to nature (emissions to air, water, and soil, and solid waste) across each life cycle stage. The quality and completeness of the LCI directly determines the reliability of the downstream LCIA results, as the LCIA phase "uses the LCI results to assess the significance of potential environmental impacts".

The LCA software and background LCI database used in a study determine how unit processes are modeled and which regionalized datasets underpin the inventory. The two PEPs compared in this study were modeled using different software and database combinations:

- BC 2 was modeled using Life Cycle Assessment for Experts (LCA FE) v.10.9 with the Managed LCA Content (MLC, 2024.2) database, both provided by Sphera Solutions, Inc.
- Galaxy Li-ion was modeled using EIME v6.1 with the EIME database version 2023-02

While the two studies use different LCA software and background databases, the PCR does not prescribe a specific LCA software or LCI database; rather, it harmonizes the methodological framework within which any compliant tool must operate. Specifically, the PCR prescribes system boundary definitions and life cycle module structure from A1-A3 through Module D (*PCR Section 2.2*), cut-off criteria of 5% for mass, energy, and environmental impact (*PCR Section 2.3*), allocation procedures per ISO 14044 paragraph 4.3.4 (*PCR Section 2.4*), functional unit and reference service life requirements (paragraph 2.1), the mandatory set of indicators (*PCR Section 2.10.1*), and the application of EC-JRC characterization factors per EN 15804:2019+A2 (*PCR Section 2.10*). Secondary data are subject to quality requirements including temporal, geographical, and technological representativeness, evaluated using the Data Quality Rating (DQR) framework (*PCR Section 2.9*). The PSR further supplements these rules by mandating the inclusion of specific materials and components regardless of mass contribution, including copper, aluminum, batteries and accumulators, and semi-conductors (*PSR Section 3.1.3*), and by requiring that the consumed power for each operating mode and the duration of operating modes be described in the PEP and justified in the accompanying report (*PSR Section 3.15.2*). The PSR also requires that the environmental database version and the Environmental Footprint (EF) version be stated in the PEP (*PSR Section 3.1.8.1*). This shared methodological framework ensures that the declared values are calculated on a comparable basis, even when the underlying software platforms and background datasets differ.

2.4 LCA stages and validity of comparison

2.4.1 Manufacturing stage (A1 to A3)

The PCR defines the manufacturing stage as inclusive of the extraction and production of raw materials; transportation and packaging of raw materials to manufacturing sites; industrial transformation and manufacturing of components and subassemblies; assembly of the reference product; production and transportation of primary and secondary packaging materials; and transportation of the packaged product to the manufacturer's last logistics platform (*PCR Section 2.2.3*). The BC 2 is assembled in Oregon, USA with batteries produced in Changsha, China, with region-specific energy models applied for each location. The Galaxy Li-ion applies an Asia Pacific electricity mix for A1-A3 processes, with the material production, manufacturing process, and transport technology modules used in the LCA declared as representative of the actual technologies used in production. **This stage is directly governed by primary manufacturer data.**

2.4.2 Distribution stage (A4)

The PCR defines the distribution stage as inclusive of transportation of the product from the manufacturer's last logistics platform to the installation place, with production, procurement, and end-of-life management of packaging materials included where appropriate *(PCR Section 2.2.4)*. The BC 2 declares distribution from the United States to Europe by ocean vessel. The Galaxy Li-ion considers United States based distribution. **The geographic scope for A4 differs fundamentally between the two PEPs, such that any numerical difference in results would reflect the declared distribution context and not only the distribution stage impact of products.**

2.4.3 Installation stage (A5)

The PCR defines the installation stage as including all flows related to the installation process (*PCR Section 2.2.5*). This covers upstream production and transport of flows generating waste; manufacturing, packaging, and procurement of materials and components not supplied with the reference product but required for installation; installation operations; and management of waste generated at the installation site, including packaging, discarded installation materials, and waste associated with the installation processes. BC 2 considers electricity consumed for commissioning at the customer site, with packaging waste treatment modeled at average European values using a European energy model. The Galaxy Li-ion uses a United States energy model. **The geographic scope and energy model for A5 differ fundamentally between the two PEPs, such that any numerical difference in results would reflect the declared installation context and not only the installation stage impact of products**.

2.4.4 Use stage (B1 to B7)

The PCR defines the use stage as covering energy consumption, water consumption, emissions, and other flows of the product during its use over the reference service life, as well as production, distribution, installation, and end of life of elements required to operate and maintain the reference product *(PCR Section 2.2.6)*. The PSR further specifies the use scenario for active products in this category, requiring declaration of consumed power for each operating mode and duration of operating modes expressed as a percentage of the full cycle time *(PSR Section 3.15.2.1)*. BC 2 states the standard use case for the declared product includes twenty-four (24) partial discharges per year over the entire reference service life to ensure the health of the batteries, in addition to constant monitoring by the Battery Management System (BMS). Additionally, the model assumes two (2) full discharges per year to provide backup power in situations where grid power is disrupted. Consequently, BC 2 declares a total electricity consumption of 4,155 kWh over the 10-year reference service life, based on 24 partial discharges and 2 full discharges per year in addition to a BMS continuous draw of 28W. For the Galaxy-Li, with the standard use case, the losses for the Battery Management System represent the largest energy use of the cabinet, at 25W per cabinet regardless of the number of battery modules. The declared annual electricity consumption is 219 kWh, resulting in a total of 2,190 kWh over the 10-year reference service life. Both PEPs identify BMS continuous power draw as the primary driver of stage electricity consumption. The two PEPs apply different geographic electricity models for the use stage, with the BC 2 applying a European model and the Galaxy Li-ion applying a United States model.

2.4.5 End-of-life stage (C1 to C4)

The PCR defines the end-of-life stage as covering deinstallation, transportation to the final treatment site, depollution, separation and preparation of material fractions, material recovery, energy recovery, and disposal *(PCR Section 2.2.7)*. The BC 2 models end-of-life to include manual dismantling, transportation, recycling operations, and disposal, with 58.8% of materials recycled in the analysis. The Galaxy Li-ion models end-of-life recycling rates calculated from the recycling rates of each material using the ESR database, with a conservative assumption of 0% recyclability applied where data is absent. The two PEPs apply different geographic energy models for the stage, with the BC 2 applying a European model and the Galaxy Li-ion applying a United States model. **As the PEPs apply different geographic scope, energy models and recycling rate calculation methodologies, any numerical difference in end-of-life results would reflect declared end-of-life context, and not only the end-of-life impact of the product.**

2.4.6 Net benefits and loads beyond the system boundaries stage (D)

The PCR defines Module D as an optional stage covering the potential for reuse, recovery, and recycling, expressed as net benefits and impacts beyond the system boundary *(PCR Section 2.2.8)*. Both PEPs declare Module D. The BC 2 declares a recyclability potential of 81.7% as supplementary product information, assuming proper dismantling of the batteries from the cabinet upon deinstallation and subsequent shipment to qualified metal scrap and battery recyclers. Declared product components are recycled or disposed of according to the PCR. For product components disposed of via incineration, thermal and electricity credits are taken at average European values. Module D credits relate to recycled materials at end of life, based on the avoidance of producing comparable material using factors such as purity or value. The Galaxy Li-ion declares a recyclability

potential of 74%. It is noted that recyclability potential is supplementary product information and not modeled in the LCA. Critically, the PCR explicitly states that "the total column of the result of the impacts calculated in the LCA shall not include the results of the net benefits and loads beyond the system boundaries stage" *(PCR Section 4.4)*.

2.5 Life Cycle Impact Assessment (LCIA)

Life Cycle Impact Assessment (LCIA) is defined as the "phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system" (*ISO 14044:2006, paragraph 3.4*). The LCIA phase translates the LCI into environmental impact scores by applying characterization factors (CFs) to the inventory flows and aggregating them into impact categories such as climate change, acidification, and eutrophication (*ISO 14044:2006; European Commission, 2021, Recommendation 2021/2279*). The two PEPs compared in this study apply different LCIA method versions:

- BC 2 applies the EF 3.1 LCIA method
- Galaxy Li-ion applies the EF 3.0 LCIA method

Both studies were conducted in compliance with ISO 14040/14044 and EN 15804+A2, and both apply the Environmental Footprint (EF) LCIA framework published by the European Commission Joint Research Centre.

Comparing environmental impact indicators across studies that apply different LCIA method versions introduces uncertainty that must be acknowledged. As documented in the Joint Research Centre (JRC) Technical Report EUR 31414 EN, "Updated Characterisation and Normalisation Factors for the Environmental Footprint 3.1 Method," published by the Publications Office of the European Union (*Andreasi Bassi et al., 2023, JRC130796*), characterization factors (CFs) of six impact categories were updated between EF 3.0 and EF 3.1. *Table 4* identifies which indicators in the declared impact set experienced a CF change and describes the nature of that change. *Table 5* provides dataset-level percentage change statistics that serve as method adjustment factors when converting EF 3.1 results to EF 3.0 results.

Table 4 Characterization factor (CF) changes between EF 3.0 and EF 3.1 for declared environmental impact indicators.

Impact Indicator	CF Change	Nature of Change	Key Driver	Scale of Change Across Datasets
Climate change, total	Yes	Underlying GWP method updated from IPCC AR5 to IPCC AR6. Methane CFs revised downward (fossil: 36.8 to 29.8; biogenic: 34 to 27). Sub-impact categories for biogenic carbon and land use change corrected for missing flows.	Methane share of product inventory	-58% to +302% across datasets; 83% lower on average (2.9%); median 2.2% lower
Climate change, fossil	Yes	Same IPCC AR6 update applies to fossil sub-indicator.	Fossil methane	Subsumed in total climate change dataset statistics
Climate change, biogenic	Yes	Previously missing biogenic flows added. CF for biogenic methane revised (34 to 27).	Biogenic methane	Subsumed in total climate change dataset statistics
Climate change, land use and land use change	Yes	Previously missing land use change flows added.	Land use change flows	Subsumed in total climate change dataset statistics
Ozone depletion	No	No CF change	N/A	N/A
Acidification	Yes	Minor. Six specific sulfur dioxide flows had incorrect CFs corrected. Missing sub-compartment assignments added.	Sulfur dioxide (CZ and AL location corrections)	Approximately 8% increase; affects only 5 of 2,752 datasets (container glass sector)
Eutrophication, freshwater	No	No CF change	N/A	N/A
Eutrophication, marine	No	No CF change	N/A	N/A
Eutrophication, terrestrial	No	No CF change	N/A	N/A

Photochemical ozone formation, human health	Yes	Synonyms "Methyl chloroform" and "Methylene chloride" assigned same CF as their parent substances.	Synonym / duplicate assignment	Zero datasets affected in practice
Resource use, minerals and metals	No	No CF change	N/A	N/A
Resource use, fossils	No	No CF change	N/A	N/A
Water use	No	No CF change	N/A	N/A

Table 5 EF 3.1 to EF 3.0 method adjustment factors for characterized results.

Environmental Impact Indicator	Median % Change (EF 3.1 vs EF 3.0)	Average % Change (EF 3.1 vs EF 3.0)	Basis
Climate change, total	-2.2%	-2.9%	Section 5.1.1.1: 2,752 datasets; 83% of datasets show lower result in EF 3.1
Climate change, fossil	Note (a)	Note (a)	Sub-indicator statistics not separately reported in JRC130796
Climate change, biogenic	Note (a)	Note (a)	Sub-indicator statistics not separately reported in JRC130796
Climate change, land use and land use change	Note (a)	Note (a)	Sub-indicator statistics not separately reported in JRC130796
Ozone depletion	N/A	N/A	No CF change between EF 3.0 and EF 3.1; no adjustment applied
Acidification	Note (b)	Note (b)	Only 5 of 2,752 datasets affected (container glass sector); no aggregate median or average reported
Eutrophication, freshwater	N/A	N/A	No CF change; no adjustment applied
Eutrophication, marine	N/A	N/A	No CF change; no adjustment applied
Eutrophication, terrestrial	N/A	N/A	No CF change; no adjustment applied
Photochemical ozone formation, human health	0%	0%	Section 5.1.1.2: zero datasets affected in practice
Resource use, minerals and metals	N/A	N/A	No CF change; no adjustment applied
Resource use, fossils	N/A	N/A	No CF change; no adjustment applied
Water use	N/A	N/A	No CF change; no adjustment applied

Note (a): The JRC report provides dataset-level percentage change statistics only for the climate change total indicator in JRC130796 Section 5.1.1.1. The three sub-indicators (fossil, biogenic, land use and land use change) share the same characterization factor update but are not analyzed separately. The climate change sub-indicators (fossil, biogenic, land use and land use change) are therefore excluded from the comparative analysis in this study.
Note (b): The acidification CF correction affects only a narrow set of sulfur dioxide flows used in container glass production. The JRC report does not provide an aggregate median or average for the full 2,752-dataset population given the highly concentrated nature of the effect. Therefore, no adjustment is applied to the acidification result.
Note (c): "N/A" indicates no CF change occurred between EF 3.0 and EF 3.1 for that indicator; the question of method adjustment does not arise, and the EF 3.1 characterized result is used directly. "0%" indicates a CF change did occur but affected zero datasets in practice (JRC130796 Section 5.1.1.2).

To enable a methodologically consistent comparison, this study applies method adjustment factors to the BC 2 environmental impact indicators to derive EF 3.0 equivalent values. The adjustment factors are the median and average percentage change values reported across 2,752 official EF datasets in Andreasi Bassi et al. (*2023, JRC130796*). Where the JRC report identifies no CF change for an indicator, or where the CF change affected zero datasets in practice, the BC 2 result is used directly without adjustment.

No such adjustment is applied to the inventory flows indicators. These are declared at the life cycle inventory level as direct aggregations of elementary flows, reported in physical units of energy, mass and volume, and no characterization factors enter their derivation. The difference between EF 3.1 and EF 3.0 is a difference in characterization factors alone, so it affects only the characterized impact indicators and cannot propagate to quantities reported without characterization.

3 Comparison of indicators

3.1 Declared indicators

This section illustrates the declared environmental impact indicators and inventory flows indicators in BC 2 and Galaxy Li-ion used for comparison in this study.

3.1.1 Environmental impact indicators

Table 6 Environmental impact indicators of BC 2.

Indicator	Units	Total (Excluding Module D)	Manufacturing	Distribution	Installation	Utilization	End of Life	Benefits/Loads
			A1-A3	A4	A5	B1-B7 (B6)	C1-C4	D
Climate Change - total	kg CO_2 eq.	9,410.000	7,110.000	301.000	78.300	1,200.000	717.000	(2,080.000)
Climate Change - fossil fuels	kg CO_2 eq.	9,290.000	7,080.000	300.000	7.150	1,190.000	714.000	(2,070.000)
Climate Change - biogenics	kg CO_2 eq.	110.000	26.600	(0.861)	71.100	10.700	2.090	(0.707)
Climate Change - land use and land use transformation	kg CO_2 eq.	10.500	7.030	1.860	0.013	0.181	1.460	(3.38)
Ozone depletion[4]	kg CFC 11 eq.	0.000	0.000	0.000	0.000	0.000	0.000	(0.000)
Acidification (AP)	Mole H+ eq.	202.000	192.000	3.770	0.024	2.290	3.410	(112.000)
Freshwater eutrophication	kg P eq.	0.025	0.016	0.001	0.001	0.005	0.003	(0.004)
Marine aquatic eutrophication	kg N eq.	10.900	7.330	1.640	0.012	0.574	1.370	(1.840)
Terrestrial eutrophication	Mole of N eq.	116.000	76.900	18.000	0.092	6.000	15.000	(19.500)
Photochemical ozone formation	kg NMVOC eq.	39.700	30.300	4.250	0.029	1.520	3.650	(11.900)
Abiotic resource depletion - metals and minerals	kg Sb eq.	0.594	0.593	0.000	0.000	0.000	0.000	(0.285)
Abiotic resource depletion - fossils	MJ	134,000.000	94,900.000	3,760.000	87.200	24,900.000	9,790.000	(26,800.000)
Water requirement	m^3 eq.	2,770.000	2,370.000	3.830	6.060	324.000	71.600	(454.000)

Table 7 Environmental impact indicators of Galaxy Li-ion.

Indicator	Units	Total (Excluding Module D)	Manufacturing	Distribution	Installation	Utilization	End of Life	Benefits/Loads
			A1-A3	A4	A5	B1-B7 (B6)	C1-C4	D
Contribution to climate change	kg CO_2 eq.	13,300.000	10,900.000	101.000	77.300	1,200.000	1,010.000	(745.000)
Contribution to climate change - fossil	kg CO_2 eq.	13,100.000	10,800.000	101.000	18.700	1,200.000	1,000.000	(740.000)
Contribution to climate change - biogenic	kg CO_2 eq.	113.000	50.100	-	58.600	1.260	2.820	(4.580)
Contribution to climate change - land use and land use change	kg CO_2 eq.	0.008	0.008	-	-	-	0.000	(0.000)
Contribution to ozone depletion	kg CFC 11 eq.	0.009	0.009	-	-	0.000	0.000	(0.000)
Contribution to acidification	Mole H+ eq.	81.100	71.300	0.641	0.019	6.340	2.750	(6.120)
Contribution to eutrophication, freshwater	kg P eq.	5.190	5.090	-	-	0.002	0.093	(0.001)
Contribution to eutrophication marine	kg N eq.	21.800	20.000	0.301	0.006	0.754	0.694	(0.440)
Contribution to eutrophication, terrestrial	Mole of N eq.	155.000	135.000	3.300	0.081	8.840	7.520	(5.120)
Contribution to photochemical ozone formation - human health	kg NMVOC eq.	48.400	42.800	0.832	0.016	2.500	2.260	(1.880)
Contribution to resource use, minerals and metals	kg Sb eq.	0.596	0.593	-	-	-	0.003	(0.230)
Contribution to resource use, fossils	MJ	189,000.000	123,000.000	1,410.000	32.600	25,400.000	39,300.000	(16,600.000)
Contribution to water use	m^3 eq.	144,000.000	144,000.000	-	-	43.000	275.000	(378.000)

Note: '-' indicates a PEP-declared value of less than 0.01% of the total life cycle of the reference flow, reported as 0 in the source PEP.*

[4] Ozone Depletion values are in the order of magnitude 10^-8 to 10^-10 kg CFC 11 eq.

3.1.2 Inventory flows indicators

This section illustrates the declared inventory flows indicators such as (i) Resource Use Indicators, (ii) Secondary Materials, Water, & Energy Resource Indicators, (iii) Waste category & Output Flow Indicators.

Table 8 Inventory flows indicators of BC 2.

Indicator	Units	Total (Excluding Module D)	Manufacturing	Distribution	Installation	Utilization	End of Life	Benefits/Loads
			A1-A3	A4	A5	B1-B7 (B6)	C1-C4	D
Use of renewable primary energy (PERE)	MJ	45,100.000	22,200.000	156.000	830.000	18,000.000	3,950.000	(4,750.000)
Primary energy resources used as raw materials (PERM)	MJ	155.000	947.000	0.000	(791.000)	0.000	0.000	(0.000)
Total use of renewable primary energy resources (PERT)	MJ	45,300.000	23,100.000	156.000	38.900	18,000.000	3,950.000	(4,750.000)
Use of non-renewable primary energy (PENRE)	MJ	130,000.000	91,400.000	3,760.000	95.600	24,900.000	9,790.000	(26,800.000)
Non-renewable primary energy resources used as raw materials (PENRM)	MJ	3,540.000	3,550.000	0.000	(8.370)	0.000	0.000	(0.000)
Total use of non-renewable primary energy resources (PENRT)	MJ	134,000.000	94,900.000	3,760.000	87.200	24,900.000	9,790.000	(26,800.000)
Input of secondary material (SM)	kg	0.000	0.000	0.000	0.000	0.000	0.000	(0.000)
Use of renewable secondary fuels (RSF)	MJ	0.000	0.000	0.000	0.000	0.000	0.000	(0.000)
Use of non renewable secondary fuels (NRSF)	MJ	0.000	0.000	0.000	0.000	0.000	0.000	(0.000)
Use of net fresh water (FW)	m^3	83.900	66.700	0.212	0.155	13.700	3.080	(16.900)
Hazardous waste disposed (HWD)	kg	0.011	0.011	0.000	0.000	0.000	0.000	(0.000)
Non-hazardous waste disposed (NHWD)	kg	2,250.000	2,000.000	0.384	25.900	20.600	210.000	(679.000)
Radioactive waste disposed (RWD)	kg	7.580	2.860	0.009	0.008	3.980	0.724	(1.070)
Components for re-use (CRU)	kg	0.000	0.000	0.000	0.000	0.000	0.000	(0.000)
Materials for Recycling (MFR)	kg	610.000	84.900	0.000	0.000	0.000	525.000	(0.000)
Material for Energy Recovery (MER)	kg	0.000	0.000	0.000	0.000	0.000	0.000	(0.000)
Exported electrical energy (EEE)	MJ	0.000	0.000	0.000	0.000	0.000	0.000	(0.000)
Exported thermal energy (EET)	MJ	0.000	0.000	0.000	0.000	0.000	0.000	(0.000)
Biogenic carbon content in product	kg	3.780	3.780	0.000	0.000	0.000	0.000	(0.000)
Biogenic carbon content in packaging	kg	33.500	33.500	0.000	0.000	0.000	0.000	(0.000)

Table 9 Inventory flows indicators of Galaxy Li-ion.

Indicator	Units	Total (Excluding Module D)	Manufacturing	Distribution	Installation	Utilization	End of Life	Benefits/Loads
			A1-A3	A4	A5	B1-B7 (B6)	C1-C4	D
Contribution to use of renewable primary energy excluding renewable primary energy used as raw material	MJ	7,110.000	3,850.000	1.890	-	3,190.000	70.500	(191.000)
Contribution to use of renewable primary energy resources used as raw material	MJ	866.000	866.000	-	-	-	-	(0.000)
Contribution to total use of renewable primary energy resources	MJ	7,980.000	4,720.000	1.890	-	3,190.000	70.500	(191.000)
Contribution to use of non renewable primary energy excluding non-renewable primary energy used as raw material	MJ	187,000.000	121,000.000	1,410.000	32.600	25,400.000	39,300.000	(16,600.000)
Contribution to use of non renewable primary energy resources used as raw material	MJ	2,240.000	2,240.000	-	-	-	-	(0.000)
Contribution to total use of non renewable primary energy resources	MJ	189,000.000	123,000.000	1,410.000	32.600	25,400.000	39,300.000	(16,600.000)
Contribution to use of secondary material	kg	0.000	0.000	-	-	-	-	(0.000)
Contribution to use of renewable secondary fuels	MJ	0.000	-	-	-	-	-	(0.000)
Contribution to use of non renewable secondary fuels	MJ	0.000	-	-	-	-	-	(0.000)
Contribution to net use of freshwater	m^3	3,360.000	3,350.000	-	-	1.000	6.410	(8.800)
Contribution to hazardous waste disposed	kg	133,000.000	133,000.000	-	-	23.400	120.000	(18,400.000)
Contribution to non hazardous waste disposed	kg	8,470.000	8,230.000	3.550	46.100	177.000	15.300	(609.000)
Contribution to radioactive waste disposed	kg	5.810	5.770	0.003	0.001	0.033	0.003	(0.293)
Contribution to components for reuse	kg	0.000	-	-	-	-	-	(0.000)
Contribution to materials for recycling	kg	227.000	30.400	-	-	-	196.000	(0.000)
Contribution to materials for energy recovery	kg	0.000	0.000	-	-	-	-	(0.000)
Contribution to exported energy	MJ	5.590	3.650	-	-	-	1.940	(0.000)
Contribution to biogenic carbon content of the product	kg of C	0.000	NA	NA	NA	NA	NA	NA
Contribution to biogenic carbon content of the associated packaging	kg of C	15.000	NA	NA	NA	NA	NA	NA

3.2 Comparison of environmental impact indicators

3.2.1 Functional unit basis

This comparison is based on functional units as described in *Table 2.*

- BC 2: To provide **37.6 kWh of backup power** to 3-Phase and other compatible UPS models for **10 years.**
- Galaxy Li-ion: To provide **34.7 kWh** of **backup power** to 3-Phase and other compatible UPS models for **10 years.**

The indicators here illustrate the impacts per functional unit of the product. Furthermore, the impact results have been adjusted as per average and median adjustment factors for EF 3.1 to EF 3.0 as mentioned in *Table 5*

3.2.1.1 EF 3.1 to EF 3.0 using median adjustment factors

Table 10 Characterization factor adjusted environmental impact indicators per functional unit (median adjustment factors).

Impact Indicator	Unit	Total (Excluding Module D)		Manufacturing		Distribution		Installation		Utilization		End of Life		Benefits and Loads	
				A1 - A3		A4		A5		B1 - B7 (B6)		C1 - C4		D	
		BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion
Climate Change - total	kg CO_2 eq.	9,621.677	13,300.000	7,269.939	10,900.000	307.771	101.000	80.061	77.300	1,226.994	1,200.000	733.129	1,010.000	(2,126.789)	(745.000)
Ozone depletion	kg CFC 11 eq.	0.000	0.009	0.000	0.009	0.000	-	0.000	-	0.000	0.000	0.000	0.000	(0.000)	(0.000)
Acidification	Mole H+ eq.	202.000	81.100	192.000	71.300	3.770	0.641	0.024	0.019	2.290	6.340	3.410	2.750	(112.000)	(6.120)
Eutrophication, freshwater	kg P eq.	0.025	5.190	0.016	5.090	0.001	-	0.001	-	0.005	0.002	0.003	0.093	(0.004)	(0.001)
Eutrophication, marine	kg N eq.	10.900	21.800	7.330	20.000	1.640	0.301	0.012	0.006	0.574	0.754	1.370	0.694	(1.840)	(0.440)
Eutrophication, terrestrial	Mole of N eq.	116.000	155.000	76.900	135.000	18.000	3.300	0.092	0.081	6.000	8.840	15.000	7.520	(19.500)	(5.120)
Photochemical ozone formation, human health	kg NMVOC eq.	39.700	48.400	30.300	42.800	4.250	0.832	0.029	0.016	1.520	2.500	3.650	2.260	(11.900)	(1.880)
Resource use, mineral and metals	kg Sb eq.	0.594	0.596	0.593	0.593	0.000	-	0.000	-	0.000	-	0.000	0.003	(0.285)	(0.230)
Resource use, fossils	MJ	134,000.000	189,000.000	94,900.000	123,000.000	3,760.000	1,410.000	87.200	32.600	24,900.000	25,400.000	9,790.000	39,300.000	(26,800.000)	(16,600.000)
Water use	m^3 eq.	2,770.000	144,000.000	2,370.000	144,000.000	3.830	-	6.060	-	324.000	43.000	71.600	275.000	(454.000)	(378.000)

Table 11 Percentage difference[5] in environmental impact indicators per functional unit (median adjustment factors).

Impact Indicator	Unit	Total (Excluding Module D)	Manufacturing	Distribution	Installation	Utilization	End of Life	Benefits & Loads
			A1-A3	A4	A5	B1-B7 (B6)	C1-C4	D
Climate Change - total	kg CO_2 eq.	-27.7%	-33.3%	-67.2%	-3.4%	-2.2%	-27.4%	+185.5%
Ozone depletion	kg CFC 11 eq.	-100.0%	-100.0%	—	—	-99.5%	-99.7%	+2942608.3%
Acidification	Mole H+ eq.	-59.9%	-62.9%	-83.0%	-19.1%	-63.9%	-19.4%	+1730.1%
Eutrophication, freshwater	kg P eq.	-99.5%	-99.7%	—	—	-62.9%	-97.3%	+247.1%
Eutrophication, marine	kg N eq.	-50.0%	-63.4%	-81.6%	-51.5%	-23.9%	-49.3%	+318.2%
Eutrophication, terrestrial	Mole of N eq.	-25.2%	-43.0%	-81.7%	-12.2%	-32.1%	-49.9%	+280.9%
Photochemical ozone formation, human health	kg NMVOC eq.	-18.0%	-29.2%	-80.4%	-45.6%	-39.2%	-38.1%	+533.0%
Resource use, minerals and metals	kg Sb eq.	-0.3%	—	—	—	—	-97.2%	+23.9%
Resource use, fossils	MJ	-29.1%	-22.8%	-62.5%	-62.6%	-2.0%	-75.1%	+61.4%
Water use	m^3 eq.	-98.1%	-98.4%	—	—	-86.7%	-74.0%	+20.1%

Note: Blue font indicates BC 2 is favorable (lower impact or larger Module D credit). Green font indicates Galaxy Li-ion is favorable (lower impact or larger Module D credit).

[5] For impact indicators (Modules A through C and Total excluding Module D), when BC 2 < Galaxy Li-ion: (BC 2 − Galaxy Li-ion) / |Galaxy Li-ion| × 100; when Galaxy Li-ion < BC 2: (Galaxy Li-ion − BC 2) / |BC 2| × 100. The denominator is the larger value, capping results between −100% and 0%. For Module D, where both declarations are negative (credits): when |BC 2| > |Galaxy Li-ion|: (|BC 2| − |Galaxy Li-ion|) / |Galaxy Li-ion| × 100; when |Galaxy Li-ion| > |BC 2|: (|Galaxy Li-ion| − |BC 2|) / |BC 2| × 100. The denominator is the smaller absolute value, so results are uncapped. Percentages from these two formulas are on different scales and are not directly comparable to each other in magnitude. Blue font indicates BC 2 is favorable (lower impact or larger Module D credit). Green font indicates Galaxy Li-ion is favorable (lower impact or larger Module D credit). '—' indicates the percentage is not defined. This occurs in three cases: the Galaxy Li-ion PEP declares 0* (less than 0.01% of the total life cycle of the reference flow), so no quantified value exists; both declarations are zero, giving 0/0; or the Galaxy Li-ion PEP stage breakdown is not available.

3.2.1.2 EF 3.1 to EF 3.0 using average adjustment factors

Table 12 Characterization factor adjusted environmental impact indicators per functional unit (average adjustment factors).

Impact Indicator	Unit	Total (Excluding Module D)		Manufacturing		Distribution		Installation		Utilization		End of Life		Benefits and Loads	
				A1 - A3		A4		A5		B1 - B7 (B6)		C1 - C4		D	
		BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion
Climate Change - total	kg CO_2 eq.	9,691.040	13,300.000	7,322.348	10,900.000	309.990	101.000	80.639	77.300	1,235.839	1,200.000	738.414	1,010.000	(2,142.122)	(745.000)
Ozone depletion	kg CFC 11 eq.	0.000	0.009	0.000	0.009	0.000	-	0.000	-	0.000	0.000	0.000	0.000	(0.000)	(0.000)
Acidification	Mole H+ eq.	202.000	81.100	192.000	71.300	3.770	0.641	0.024	0.019	2.290	6.340	3.410	2.750	(112.000)	(6.120)
Eutrophication, freshwater	kg P eq.	0.025	5.190	0.016	5.090	0.001	-	0.001	-	0.005	0.002	0.003	0.093	(0.004)	(0.001)
Eutrophication, marine	kg N eq.	10.900	21.800	7.330	20.000	1.640	0.301	0.012	0.006	0.574	0.754	1.370	0.694	(1.840)	(0.440)
Eutrophication, terrestrial	Mole of N eq.	116.000	155.000	76.900	135.000	18.000	3.300	0.092	0.081	6.000	8.840	15.000	7.520	(19.500)	(5.120)
Photochemical ozone formation, human health	kg NMVOC eq.	39.700	48.400	30.300	42.800	4.250	0.832	0.029	0.016	1.520	2.500	3.650	2.260	(11.900)	(1.880)
Resource use, mineral and metals	kg Sb eq.	0.594	0.596	0.593	0.593	0.000	-	0.000	-	0.000	-	0.000	0.003	(0.285)	(0.230)
Resource use, fossils	MJ	134,000.000	189,000.000	94,900.000	123,000.000	3,760.000	1,410.000	87.200	32.600	24,900.000	25,400.000	9,790.000	39,300.000	(26,800.000)	(16,600.000)
Water use	m^3 eq.	2,770.000	144,000.000	2,370.000	144,000.000	3.830	-	6.060	-	324.000	43.000	71.600	275.000	(454.000)	(378.000)

Table 13 Percentage difference in environmental impact indicators per functional unit (average adjustment factors).

Impact Indicator	Unit	Total (Excluding Module D)	Manufacturing	Distribution	Installation	Utilization	End of Life	Benefits & Loads
			A1-A3	A4	hA5	B1-B7 (B6)	C1-C4	D
Climate Change - total	kg CO_2 eq.	-27.1%	-32.8%	-67.4%	-4.1%	-2.9%	-26.9%	+187.5%
Ozone depletion	kg CFC 11 eq.	-100.0%	-100.0%	—	—	-99.5%	-99.7%	+2942608.3%
Acidification	Mole H+ eq.	-59.9%	-62.9%	-83.0%	-19.1%	-63.9%	-19.4%	+1730.1%
Eutrophication, freshwater	kg P eq.	-99.5%	-99.7%	—	—	-62.9%	-97.3%	+247.1%
Eutrophication, marine	kg N eq.	-50.0%	-63.4%	-81.6%	-51.5%	-23.9%	-49.3%	+318.2%
Eutrophication, terrestrial	Mole of N eq.	-25.2%	-43.0%	-81.7%	-12.2%	-32.1%	-49.9%	+280.9%
Photochemical ozone formation, human health	kg NMVOC eq.	-18.0%	-29.2%	-80.4%	-45.6%	-39.2%	-38.1%	+533.0%
Resource use, minerals and metals	kg Sb eq.	-0.3%	—	—	—	—	-97.2%	+23.9%
Resource use, fossils	MJ	-29.1%	-22.8%	-62.5%	-62.6%	-2.0%	-75.1%	+61.4%
Water use	m^3 eq.	-98.1%	-98.4%	—	—	-86.7%	-74.0%	+20.1%

3.2.2 kWh basis

BC 2 declared environmental impact indicators are expressed per 1 kWh of backup power for service life by dividing the functional unit values by 37.6 kWh. Galaxy Li-ion declared environmental impact indicators are expressed per 1 kWh of backup power for service life by dividing the functional unit values by 34.7 kWh. Hence, the indicators here illustrate the impacts per kWh of backup power of the product.

3.2.2.1 EF 3.1 to EF 3.0 using median adjustment factors

Table 14 Characterization factor adjusted environmental impact indicators per kWh of backup power for service life (median adjustment factors).

Impact Indicator	Unit	Total (Excluding Module D)		Manufacturing		Distribution		Installation		Utilization		End of Life		Benefits and Loads	
				A1 - A3		A4		A5		B1 - B7 (B6)		C1 - C4		D	
		BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion
Climate Change - total	kg CO_2 eq.	255.896	383.285	193.349	314.121	8.185	2.911	2.129	2.228	32.633	34.582	19.498	29.107	(56.564)	(21.470)
Ozone depletion	kg CFC 11 eq.	0.000	0.000	0.000	0.000	0.000	-	0.000	-	0.000	0.000	0.000	0.000	(0.000)	(0.000)
Acidification	Mole H+ eq.	5.372	2.337	5.106	2.055	0.100	0.018	0.000628	0.000550	0.061	0.183	0.091	0.079	(2.979)	(0.176)
Eutrophication, freshwater	kg P eq.	0.001	0.150	0.000	0.147	0.000	-	0.000	-	0.000	0.000	0.000	0.003	(0.000)	(0.000)
Eutrophication, marine	kg N eq.	0.290	0.628	0.195	0.576	0.044	0.009	0.000322	0.000169	0.015	0.022	0.036	0.020	(0.049)	(0.013)
Eutrophication, terrestrial	Mole of N eq.	3.085	4.467	2.045	3.890	0.479	0.095	0.002	0.002	0.160	0.255	0.399	0.217	(0.519)	(0.148)
Photochemical ozone formation, human health	kg NMVOC eq.	1.056	1.395	0.806	1.233	0.113	0.024	0.000782	0.000461	0.040	0.072	0.097	0.065	(0.316)	(0.054)
Resource use, mineral and metals	kg Sb eq.	0.016	0.017	0.016	0.017	0.000001	-	0.000000	-	0.000006	-	0.000002	0.000083	(0.008)	(0.007)
Resource use, fossils	MJ	3,563.830	5,446.686	2,523.936	3,544.669	100.000	40.634	2.319	0.939	662.234	731.988	260.372	1,132.565	(712.766)	(478.386)
Water use	m^3 eq.	73.670	4,149.856	63.032	4,149.856	0.102	-	0.161	-	8.617	1.239	1.904	7.925	(12.074)	(10.893)

Table 15 Percentage difference in environmental impact indicators per kWh of backup power for service life (median adjustment factors).

Impact Indicator	Unit	Total (Excluding Module D)	Manufacturing	Distribution	Installation	Utilization	End of Life	Benefits & Loads
			A1-A3	A4	A5	B1-B7 (B6)	C1-C4	D
Climate Change - total	kg CO_2 eq.	-33.2%	-38.4%	-64.4%	-4.4%	-5.6%	-33.0%	+163.5%
Ozone depletion	kg CFC 11 eq.	-100.0%	-100.0%	—	—	-99.5%	-99.7%	+3188540.7%
Acidification	Mole H+ eq.	-56.5%	-59.8%	-81.6%	-12.3%	-66.7%	-12.6%	+1588.9%
Eutrophication, freshwater	kg P eq.	-99.6%	-99.7%	—	—	-59.8%	-97.5%	+220.3%
Eutrophication, marine	kg N eq.	-53.9%	-66.2%	-80.1%	-47.4%	-29.7%	-45.1%	+285.9%
Eutrophication, terrestrial	Mole of N eq.	-30.9%	-47.4%	-80.1%	-4.8%	-37.4%	-45.7%	+251.5%
Photochemical ozone formation, human health	kg NMVOC eq.	-24.3%	-34.7%	-78.8%	-41.0%	-43.9%	-32.9%	+484.2%
Resource use, minerals and metals	kg Sb eq.	-8.0%	-7.7%	—	—	—	-97.4%	+14.4%
Resource use, fossils	MJ	-34.6%	-28.8%	-59.4%	-59.5%	-9.5%	-77.0%	+49.0%
Water use	m^3 eq.	-98.2%	-98.5%	—	—	-85.6%	-76.0%	+10.8%

3.2.2.2 EF 3.1 to EF 3.0 using average adjustment factors

Table 16 Characterization factor adjusted environmental impact indicators per kWh of backup power for service life (average adjustment factors).

Impact Indicator	Unit	Total (excl. Module D)		Manufacturing		Distribution		Installation		Utilization		End of Life		Benefits and Loads	
				A1 - A3		A4		A5		B1 - B7 (B6)		C1 - C4		D	
		BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion
Climate Change - total	kg CO_2 eq.	257.740	383.285	194.743	314.121	8.244	2.911	2.145	2.228	32.868	34.582	19.639	29.107	(56.971)	(21.470)
Ozone depletion	kg CFC 11 eq.	0.000	0.000	0.000	0.000	0.000	-	0.000	-	0.000	0.000	0.000	0.000	(0.000)	(0.000)
Acidification	Mole H+ eq.	5.372	2.337	5.106	2.055	0.100	0.018	0.000628	0.000550	0.061	0.183	0.091	0.079	(2.979)	(0.176)
Eutrophication, freshwater	kg P eq.	0.001	0.150	0.000	0.147	0.000	-	0.000	-	0.000	0.000	0.000	0.003	(0.000)	(0.000)
Eutrophication, marine	kg N eq.	0.290	0.628	0.195	0.576	0.044	0.009	0.000322	0.000169	0.015	0.022	0.036	0.020	(0.049)	(0.013)
Eutrophication, terrestrial	Mole of N eq.	3.085	4.467	2.045	3.890	0.479	0.095	0.002	0.002	0.160	0.255	0.399	0.217	(0.519)	(0.148)
Photochemical ozone formation, human health	kg NMVOC eq.	1.056	1.395	0.806	1.233	0.113	0.024	0.000782	0.000461	0.040	0.072	0.097	0.065	(0.316)	(0.054)
Resource use, mineral and metals	kg Sb eq.	0.016	0.017	0.016	0.017	0.000001	-	0.000000	-	0.000006	-	0.000002	0.000083	(0.008)	(0.007)
Resource use, fossils	MJ	3,563.830	5,446.686	2,523.936	3,544.669	100.000	40.634	2.319	0.939	662.234	731.988	260.372	1,132.565	(712.766)	(478.386)
Water use	m^3 eq.	73.670	4,149.856	63.032	4,149.856	0.102	-	0.161	-	8.617	1.239	1.904	7.925	(12.074)	(10.893)

Table 17 Percentage difference in environmental impact indicators per kWh of backup power for service life (average adjustment factors).

Impact Indicator	Unit	Total (excl. Module D)	Manufacturing	Distribution	Installation	Utilization	End of Life	Benefits & Loads
			A1-A3	A4	A5	B1-B7 (B6)	C1-C4	D
Climate Change - total	kg CO_2 eq.	-32.8%	-38.0%	-64.7%	-3.7%	-5.0%	-32.5%	+165.4%
Ozone depletion	kg CFC 11 eq.	-100.0%	-100.0%	—	—	-99.5%	-99.7%	+3188540.7%
Acidification	Mole H+ eq.	-56.5%	-59.8%	-81.6%	-12.3%	-66.7%	-12.6%	+1588.9%
Eutrophication, freshwater	kg P eq.	-99.6%	-99.7%	—	—	-59.8%	-97.5%	+220.3%
Eutrophication, marine	kg N eq.	-53.9%	-66.2%	-80.1%	-47.4%	-29.7%	-45.1%	+285.9%
Eutrophication, terrestrial	Mole of N eq.	-30.9%	-47.4%	-80.1%	-4.8%	-37.4%	-45.7%	+251.5%
Photochemical ozone formation, human health	kg NMVOC eq.	-24.3%	-34.7%	-78.8%	-41.0%	-43.9%	-32.9%	+484.2%
Resource use, minerals and metals	kg Sb eq.	-8.0%	-7.7%	—	—	—	-97.4%	+14.4%
Resource use, fossils	MJ	-34.6%	-28.8%	-59.4%	-59.5%	-9.5%	-77.0%	+49.0%
Water use	m^3 eq.	-98.2%	-98.5%	—	—	-85.6%	-76.0%	+10.8%

3.3 Comparison of inventory flows indicators

No characterization factor adjustment is applied to these indicators. Inventory flows indicators are declared at the life cycle inventory level as direct aggregations of elementary flows, reported in physical units of energy, mass and volume, and no characterization factors enter their derivation. The difference between EF 3.1 (used by BC 2) and EF 3.0 (used by Galaxy Li-ion) is a difference in characterization factors alone. It therefore affects only the characterized impact indicators and cannot propagate to quantities reported without characterization.

3.3.1 Functional unit basis

Table 18 Inventory flows indicators per functional unit.

Indicator	Unit	Total (Excluding Module D)		Manufacturing		Distribution		Installation		Utilization		End of Life		Benefits and Loads	
				A1 - A3		A4		A5		B1 - B7 (B6)		C1 - C4		D	
		BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion
Use of renewable primary energy (PERE)	MJ	45,100.000	7,110.000	22,200.000	3,850.000	156.000	1.890	830.000	-	18,000.000	3,190.000	3,950.000	70.500	(4,750.000)	(191.000)
Primary energy resources used as raw materials (PERM)	MJ	155.000	866.000	947.000	866.000	0.000	-	(791.000)	-	0.000	-	0.000	-	(0.000)	(0.000)
Total use of renewable primary energy resources (PERT)	MJ	45,300.000	7,980.000	23,100.000	4,720.000	156.000	1.890	38.900	-	18,000.000	3,190.000	3,950.000	70.500	(4,750.000)	(191.000)
Use of non-renewable primary energy (PENRE)	MJ	130,000.000	187,000.000	91,400.000	121,000.000	3,760.000	1,410.000	95.600	32.600	24,900.000	25,400.000	9,790.000	39,300.000	(26,800.000)	(16,600.000)
Non-renewable primary energy resources used as raw materials (PENRM)	MJ	3,540.000	2,240.000	3,550.000	2,240.000	0.000	-	(8.370)	-	0.000	-	0.000	-	(0.000)	(0.000)
Total use of non-renewable primary energy resources (PENRT)	MJ	134,000.000	189,000.000	94,900.000	123,000.000	3,760.000	1,410.000	87.200	32.600	24,900.000	25,400.000	9,790.000	39,300.000	(26,800.000)	(16,600.000)
Input of secondary material (SM)	kg	0.000	0.000	0.000	0.000	0.000	-	0.000	-	0.000	-	0.000	-	(0.000)	(0.000)
Use of renewable secondary fuels (RSF)	MJ	0.000	0.000	0.000	-	0.000	-	0.000	-	0.000	-	0.000	-	(0.000)	(0.000)
Use of non renewable secondary fuels (NRSF)	MJ	0.000	0.000	0.000	-	0.000	-	0.000	-	0.000	-	0.000	-	(0.000)	(0.000)
Use of net fresh water (FW)	m^3	83.900	3,360.000	66.700	3,350.000	0.212	-	0.155	-	13.700	1.000	3.080	6.410	(16.900)	(8.800)
Hazardous waste disposed (HWD)	kg	0.011	133,000.000	0.011	133,000.000	0.000	-	0.000	-	0.000	23.400	0.000	120.000	(0.000)	(18,400.000)
Non-hazardous waste disposed (NHWD)	kg	2,250.000	8,470.000	2,000.000	8,230.000	0.384	3.550	25.900	46.100	20.600	177.000	210.000	15.300	(679.000)	(609.000)
Radioactive waste disposed (RWD)	kg	7.580	5.810	2.860	5.770	0.009	0.003	0.008	0.001	3.980	0.033	0.724	0.003	(1.070)	(0.293)
Components for re-use (CRU)	kg	0.000	0.000	0.000	-	0.000	-	0.000	-	0.000	-	0.000	-	(0.000)	(0.000)
Materials for recycling (MFR)	kg	610.000	227.000	84.900	30.400	0.000	-	0.000	-	0.000	-	525.000	196.000	(0.000)	(0.000)
Materials for energy recovery (MER)	kg	0.000	0.000	0.000	0.000	0.000	-	0.000	-	0.000	-	0.000	-	(0.000)	(0.000)
Exported energy (EE)[6]	MJ	0.000	5.590	0.000	3.650	0.000	-	0.000	-	0.000	-	0.000	1.940	(0.000)	(0.000)
Biogenic carbon content in product	kg	3.780	0.000	3.780	NA	0.000	NA	0.000	NA	0.000	NA	0.000	NA	(0.000)	NA
Biogenic carbon content in packaging	kg	33.500	15.000	33.500	NA	0.000	NA	0.000	NA	0.000	NA	0.000	NA	(0.000)	NA

[6] BC 2 reports separate Exported electrical energy (EEE) and Exported thermal energy (EET), both 0.000 MJ; combined as Exported energy (EE) for comparison.

Table 19 Percentage difference in inventory flows indicators per functional unit.

Inventory Flow Indicator	Unit	Total (Excluding Module D)	Manufacturing	Distribution	Installation	Utilization	End of Life	Benefits & Loads
			A1-A3	A4	A5	B1-B7 (B6)	C1-C4	D
Use of renewable primary energy (PERE)	MJ	+534.3%	+476.6%	+8154.0%	—	+464.3%	+5502.8%	+2386.9%
Primary energy resources used as raw materials (PERM)	MJ	+458.7%	+9.4%	—	—	—	—	—
Total use of renewable primary energy resources (PERT)	MJ	+467.7%	+389.4%	+8154.0%	—	+464.3%	+5502.8%	+2386.9%
Use of non-renewable primary energy (PENRE)	MJ	-30.5%	-24.5%	-62.5%	-65.9%	-2.0%	-75.1%	+61.4%
Non-renewable primary energy resources used as raw materials (PENRM)	MJ	-36.7%	-36.9%	—	—	—	—	—
Total use of non-renewable primary energy resources (PENRT)	MJ	-29.1%	-22.8%	-62.5%	-62.6%	-2.0%	-75.1%	+61.4%
Input of secondary material (SM)	kg	—	—	—	—	—	—	—
Use of renewable secondary fuels (RSF)	MJ	—	—	—	—	—	—	—
Use of non renewable secondary fuels (NRSF)	MJ	—	—	—	—	—	—	—
Use of net fresh water (FW)	m^3	-97.5%	-98.0%	—	—	-92.7%	-52.0%	+92.0%
Hazardous waste disposed (HWD)	kg	-100.0%	-100.0%	—	—	-100.0%	-100.0%	+262482168231.0%
Non-hazardous waste disposed (NHWD)	kg	-73.4%	-75.7%	-89.2%	-43.8%	-88.4%	-92.7%	+11.5%
Radioactive waste disposed (RWD)	kg	-23.4%	-50.4%	-72.7%	-82.1%	-99.2%	-99.6%	+265.2%
Components for re-use (CRU)	kg	—	—	—	—	—	—	—
Materials for recycling (MFR)	kg	+168.7%	+179.3%	—	—	—	+167.9%	—
Materials for energy recovery (MER)[7]	kg	—	—	—	—	—	—	—
Exported energy (EE)	MJ	—	—	—	—	—	—	—
Biogenic carbon content in product	kg	—	—	—	—	—	—	—
Biogenic carbon content in packaging	kg	—	—	—	—	—	—	—

Note: Two percentage difference formulas are applied depending on whether a lower or higher value is favorable for the indicator category.
Lower is favorable (PENRE, PENRM, PENRT, FW, HWD, NHWD, RWD): When BC 2 < Galaxy Li-ion, the percentage difference is (BC 2 − Galaxy Li-ion) / |Galaxy Li-ion| × 100. When Galaxy Li-ion < BC 2, the percentage difference is (Galaxy Li-ion − BC 2) / |BC 2| × 100. The denominator is the larger value. Results range from −100% to 0%.
Higher is favorable (PERE, PERM, PERT, MFR) and Module D: When |BC 2| > |Galaxy Li-ion|, the percentage difference is (|BC 2| − |Galaxy Li-ion|) / |Galaxy Li-ion| × 100. When |Galaxy Li-ion| > |BC 2|, the percentage difference is (|Galaxy Li-ion| − |BC 2|) / |BC 2| × 100. The denominator is the smaller absolute value. Results are uncapped.

[7] For SM (Input of secondary material), MER (Materials for energy recovery), and EE (Exported energy), Galaxy Li-ion declares non-zero values while BC 2 declares zero across all life cycle stages. Greater use of secondary materials, greater recovery of materials for energy, and greater export of energy represent environmentally favorable outcomes. Galaxy Li-ion is favorable in all three categories; however, a percentage difference cannot be computed because the denominator in the formula is zero when one declaration is zero and the other is non-zero.

3.3.2 kWh basis

BC 2 declared inventory flows indicators are expressed per 1 kWh of backup power for service life by dividing the functional unit values by 37.6 kWh. Galaxy Li-ion inventory flows indicators are expressed per 1 kWh of backup power for service life by dividing the functional unit values by 34.7 kWh. Hence, the indicators here illustrate the impacts per kWh of backup power of the product.

Table 20 Inventory flows indicators per kWh of backup power for service life.

Indicator	Unit	Total (Excluding Module D)		Manufacturing		Distribution		Installation		Utilization		End of Life		Benefits and Loads	
				A1 - A3		A4		A5		B1 - B7 (B6)		C1 - C4		D	
		BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion	BC 2	Galaxy Li-ion
Use of renewable primary energy (PERE)	MJ	1,199.468	204.899	590.426	110.951	4.149	0.054	22.074	-	478.723	91.931	105.053	2.032	(126.330)	(5.504)
Primary energy resources used as raw materials (PERM)	MJ	4.122	24.957	25.186	24.957	0.000	-	(21.037)	-	0.000	-	0.000	-	(0.000)	(0.000)
Total use of renewable primary energy resources (PERT)	MJ	1,204.787	229.971	614.362	136.023	4.149	0.054	1.035	-	478.723	91.931	105.053	2.032	(126.330)	(5.504)
Use of non-renewable primary energy (PENRE)	MJ	3,457.447	5,389.049	2,430.851	3,487.032	100.000	40.634	2.543	0.939	662.234	731.988	260.372	1,132.565	(712.766)	(478.386)
Non-renewable primary energy resources used as raw materials (PENRM)	MJ	94.149	64.553	94.415	64.553	0.000	-	(0.223)	-	0.000	-	0.000	-	(0.000)	(0.000)
Total use of non-renewable primary energy resources (PENRT)	MJ	3,563.830	5,446.686	2,523.936	3,544.669	100.000	40.634	2.319	0.939	662.234	731.988	260.372	1,132.565	(712.766)	(478.386)
Input of secondary material (SM)	kg	0.000	0.000	0.000	0.000	0.000	-	0.000	-	0.000	-	0.000	-	(0.000)	(0.000)
Use of renewable secondary fuels (RSF)	MJ	0.000	0.000	0.000	-	0.000	-	0.000	-	0.000	-	0.000	-	(0.000)	(0.000)
Use of non renewable secondary fuels (NRSF)	MJ	0.000	0.000	0.000	-	0.000	-	0.000	-	0.000	-	0.000	-	(0.000)	(0.000)
Use of net fresh water (FW)	m^3	2.231	96.830	1.774	96.542	0.006	-	0.004	-	0.364	0.029	0.082	0.185	(0.449)	(0.254)
Hazardous waste disposed (HWD)	kg	0.000	3,832.853	0.000	3,832.853	0.000	-	0.000	-	0.000	0.674	0.000	3.458	(0.000)	(530.259)
Non-hazardous waste disposed (NHWD)	kg	59.840	244.092	53.191	237.176	0.010	0.102	0.689	1.329	0.548	5.101	5.585	0.441	(18.059)	(17.550)
Radioactive waste disposed (RWD)	kg	0.202	0.167	0.076	0.166	0.000	0.000	0.000	0.000	0.106	0.001	0.019	0.000	(0.028)	(0.008)
Components for re-use (CRU)	kg	0.000	0.000	0.000	-	0.000	-	0.000	-	0.000	-	0.000	-	(0.000)	(0.000)
Materials for recycling (MFR)	kg	16.223	6.542	2.258	0.876	0.000	-	0.000	-	0.000	-	13.963	5.648	(0.000)	(0.000)
Materials for energy recovery (MER)	kg	0.000	0.000	0.000	0.000	0.000	-	0.000	-	0.000	-	0.000	-	(0.000)	(0.000)
Exported energy (EE)	MJ	0.000	0.161	0.000	0.105	0.000	-	0.000	-	0.000	-	0.000	0.056	(0.000)	(0.000)
Biogenic carbon content in product	kg	0.101	0.000	0.101	NA	0.000	NA	0.000	NA	0.000	NA	0.000	NA	(0.000)	NA
Biogenic carbon content in packaging	kg	0.891	0.432	0.891	NA	0.000	NA	0.000	NA	0.000	NA	0.000	NA	(0.000)	NA

Table 21 Percentage difference in inventory flows indicators per kWh of backup power for service life.

Inventory Flow Indicator	Unit	Total (Excluding Module D)	Manufacturing	Distribution	Installation	Utilization	End of Life	Benefits & Loads
			A1-A3	A4	A5	B1-B7 (B6)	C1-C4	D
Use of renewable primary energy (PERE)	MJ	+485.4%	+432.1%	+7517.4%	—	+420.7%	+5070.7%	+2195.1%
Primary energy resources used as raw materials (PERM)	MJ	+505.4%	+0.9%	—	—	—	—	—
Total use of renewable primary energy resources (PERT)	MJ	+423.9%	+351.7%	+7517.4%	—	+420.7%	+5070.7%	+2195.1%
Use of non-renewable primary energy (PENRE)	MJ	-35.8%	-30.3%	-59.4%	-63.0%	-9.5%	-77.0%	+49.0%
Non-renewable primary energy resources used as raw materials (PENRM)	MJ	-31.4%	-31.6%	—	—	—	—	—
Total use of non-renewable primary energy resources (PENRT)	MJ	-34.6%	-28.8%	-59.4%	-59.5%	-9.5%	-77.0%	+49.0%
Input of secondary material (SM)	kg	—	—	—	—	—	—	—
Use of renewable secondary fuels (RSF)	MJ	—	—	—	—	—	—	—
Use of non renewable secondary fuels (NRSF)	MJ	—	—	—	—	—	—	—
Use of net fresh water (FW)	m^3	-97.7%	-98.2%	—	—	-92.1%	-55.7%	+77.2%
Hazardous waste disposed (HWD)	kg	-100.0%	-100.0%	—	—	-100.0%	-100.0%	+284418718322.0%
Non-hazardous waste disposed (NHWD)	kg	-75.5%	-77.6%	-90.0%	-48.2%	-89.3%	-92.1%	+2.9%
Radioactive waste disposed (RWD)	kg	-16.9%	-54.3%	-70.4%	-80.6%	-99.1%	-99.5%	+237.0%
Components for re-use (CRU)	kg	—	—	—	—	—	—	—
Materials for recycling (MFR)	kg	+148.0%	+157.7%	—	—	—	+147.2%	—
Materials for energy recovery (MER)	kg	—	—	—	—	—	—	—
Exported energy (EE)	MJ	—	—	—	—	—	—	—
Biogenic carbon content in product	kg	—	—	—	—	—	—	—
Biogenic carbon content in packaging	kg	—	—	—	—	—	—	—

4 Summary of Results

The key findings from the comparison are as stated below. For results on all compared indicators for functional unit basis and kWh basis across all stages refer to *Section 3*, *Table 22* and *Table 23*.

1. Climate Change
    a. For this indicator, a lower value represents lower global warming potential.
    b. On a per-kWh basis, BC 2 has a Climate Change impact (Total excluding Module D) of 255.9 to 257.7 kg CO_2 eq./kWh, compared to 383.3 kg CO_2 eq./kWh for Galaxy Li-ion, a difference of 32.8% to 33.2%. BC 2 is 0.7x Galaxy Li-ion.
    c. At the manufacturing stage (A1-A3), BC 2 has a Climate Change impact of 193.3 to 194.7 kg CO_2 eq./kWh compared to 314.1 kg CO_2 eq./kWh for Galaxy Li-ion, a difference of 38.0% to 38.4%.
    d. The manufacturing stage accounts for the largest share of each product's total Climate Change impact.
2. Acidification
    a. For this indicator, a lower value represents lower acidification potential.
    b. On a per-kWh basis, Galaxy Li-ion has an Acidification total (Total excluding Module D) of 2.34 Mole H+ eq./kWh, compared to 5.37 Mole H+ eq./kWh for BC 2, a difference of 56.5%. Galaxy Li-ion is 0.4x BC 2.
    c. At the manufacturing stage (A1-A3), the difference is 59.8%.
    d. At Module D, BC 2 has a credit of 2.98 Mole H+ eq./kWh compared to 0.18 Mole H+ eq./kWh for Galaxy Li-ion. Acidification is the only environmental impact indicator where Galaxy Li-ion has a lower total (excluding Module D) on a per-kWh basis.
3. Use of non-renewable primary energy (PENRE), Non-renewable primary energy resources used as raw materials (PENRM), and Total use of non-renewable primary energy resources (PENRT)
    a. For these indicators, a lower value represents lower use of non-renewable primary energy resources.
    b. On a per-kWh basis, BC 2 has a PENRE (Total excluding Module D) of 3,457 MJ/kWh compared to 5,389 MJ/kWh for Galaxy Li-ion, a difference of 35.8% (BC 2 is 0.6x Galaxy Li-ion).
    c. PENRT follows a similar pattern, with BC 2 (Total excluding Module D) at 3,564 MJ/kWh compared to 5,447 MJ/kWh for Galaxy Li-ion, a difference of 34.6% (BC 2 is 0.7x Galaxy Li-ion).
    d. PENRM shows the reverse pattern; Galaxy Li-ion uses 64.6 MJ/kWh compared to 94.1 MJ/kWh for BC 2, a difference of 31.4% (Galaxy Li-ion is 0.7x BC 2).
    e. At Module D, BC 2 has PENRE and PENRT credits that are 1.5 times larger in absolute value than those of Galaxy Li-ion on a per-kWh basis.
4. Use of renewable primary energy (PERE), Primary energy resources used as raw materials (PERM), and Total use of renewable primary energy resources (PERT)
    a. For these indicators, a higher value represents greater use of renewable primary energy resources.
    b. On a per-kWh basis, BC 2 has PERE (Total excluding Module D) of 1,199 MJ/kWh compared to 205 MJ/kWh for Galaxy Li-ion (BC 2 is 5.9x Galaxy Li-ion), a difference of 485.4%.
    c. PERT follows a similar pattern, with BC 2 (Total excluding Module D) at 1,205 MJ/kWh compared to 230 MJ/kWh for Galaxy Li-ion (BC 2 is 5.2x Galaxy Li-ion), a difference of 423.9%.
    d. PERM shows the reverse pattern: Galaxy Li-ion uses 25.0 MJ/kWh compared to 4.1 MJ/kWh for BC 2 (Galaxy Li-ion is 6.1x BC 2), a difference of 505.4%.
    e. The PERE and PERT differences are consistent across life cycle stages, with BC 2 having values 4.5 to 5.3 times those of Galaxy Li-ion at A1-A3 and up to 23 times at Module D.
5. Use of net fresh water (FW)
    a. For this indicator, a lower value represents lower net fresh water use.
    b. On a per-kWh basis, BC 2 has a FW (Total excluding Module D) of 2.2 m^3/kWh compared to 96.8 m^3/kWh for Galaxy Li-ion, a difference of 97.7% (BC 2 is 0.02x Galaxy Li-ion).
    c. At the manufacturing stage (A1-A3), BC 2 uses 1.8 m^3/kWh compared to 96.5 m^3/kWh for Galaxy Li-ion, a difference of 98.2%.

6. Materials for recycling (MFR)
    a. For this indicator, a higher value represents a greater output flow of materials leaving the product system boundary that are destined for reuse or recycling.
    b. On a per-kWh basis, BC 2 has an MFR (Total excluding Module D) of 16.2 kg/kWh compared to 6.5 kg/kWh for Galaxy Li-ion (BC 2 is 2.5x Galaxy Li-ion), a difference of 148.0%. This difference is split between the manufacturing stage (A1-A3), where BC 2 is 2.6 times Galaxy Li-ion, and the end-of-life stage (C1-C4), where BC 2 is 2.5 times Galaxy Li-ion. Neither product has MFR at Module D.
7. Hazardous waste disposed (HWD)
    a. For this indicator, a lower value represents less hazardous waste sent to disposal.
    b. On a per-kWh basis, BC 2 has an HWD (Total excluding Module D) of 2.79×10^{-4} kg/kWh compared to 3,833 kg/kWh for Galaxy Li-ion. HWD differs by several orders of magnitude between the two products.
    c. At Module D, the relationship reverses; Galaxy Li-ion has an HWD credit of 530 kg/kWh compared to 1.86×10^{-7} kg/kWh for BC 2.
8. Input of secondary material (SM), Materials for energy recovery (MER), and Exported energy (EE)
    a. For these indicators, higher values represent greater use of secondary materials, greater output flow of materials leaving the product system for energy recovery, and greater energy export, respectively.
    b. Galaxy Li-ion has non-zero values for SM (4.12×10^{-5} kg per functional cabinet), MER (1.26×10^{-7} kg per functional cabinet), and EE (5.59 MJ per functional cabinet) at the total life cycle level, while BC 2 has zero for all three indicators across all life cycle stages. Galaxy Li-ion is favorable in these categories. The percentage difference cannot be computed because the BC 2 values are zero.
9. Trends in LCA stages
    a. Environmental impact indicators
        i. For Total excluding Module D, BC 2 has lower impact in 9 of 10 environmental impact indicators on a per-kWh basis, with Acidification being the exception.
        ii. At the manufacturing stage (A1-A3), BC 2 has lower impact in 9 of 10 environmental impact indicators, again with Acidification being the exception.
        iii. At the distribution stage (A4), Galaxy Li-ion has lower impact in all computable environmental impact indicators (6 of 10; the remaining 4 are undefined due to Galaxy Li-ion 0* declarations).
        iv. At the installation stage (A5), Galaxy Li-ion has lower impact in 5 of 6 computable indicators.
    b. Inventory flows indicators
        i. For Total excluding Module D, BC 2 is favorable in 8 of 11 computable inventory flows indicators on a per-kWh basis.
        ii. Galaxy Li-ion is favorable in PENRM, PERM, and RWD. SM, MER, and EE are excluded from percentage difference calculations as BC 2 has zero across all stages; Galaxy Li-ion is favorable in all three.
        iii. At the manufacturing stage (A1-A3), BC 2 is favorable in 10 of 11 computable indicators, with PENRM being the exception. At A4 and A5, many inventory flows indicators are undefined due to Galaxy Li-ion 0* declarations; among the computable indicators, the results are mixed.
    c. Geographic and energy model context
        i. The A4 and A5 stage-level differences should be interpreted in the context of the differing geographic scopes stated in each PEP: BC 2 has distribution from the United States to Europe, while Galaxy Li-ion has United States-based distribution. The energy models also differ, with BC 2 applying a European energy model and Galaxy Li-ion applying a United States energy model at the installation and use stages.
        ii. Additionally, the two PEPs were modeled using different LCA software and background LCI databases (LCA FE v.10.9 with MLC 2024.2 for BC 2; EIME v6.1 with EIME 2023-02 for Galaxy Li-ion), which may contribute to differences in regionalized process data and waste classification across all stages.

Table 22 Comparison summary of environmental impact indicators.

Impact Indicator	Unit	Total (excl. Module D)		Manufacturing (A1-A3)		Distribution (A4)		Installation (A5)		Utilization (B1-B7)		End of Life (C1-C4)		Benefits and Loads (D)	
		Functional unit	Per kWh	Functional unit	Per kWh	Functional unit	Per kWh	Functional unit	Per kWh	Functional unit	Per kWh	Functional unit	Per kWh	Functional unit	Per kWh
Climate Change - total	kg CO_2 eq.	BC 2 is 0.7x to 0.7x Galaxy Li-ion	BC 2 is 0.7x to 0.7x Galaxy Li-ion	BC 2 is 0.7x to 0.7x Galaxy Li-ion	BC 2 is 0.6x to 0.6x Galaxy Li-ion	Galaxy Li-ion is 0.3x to 0.3x BC 2	Galaxy Li-ion is 0.4x to 0.4x BC 2	Galaxy Li-ion is 1.0x to 1.0x BC 2	BC 2 is 1.0x to 1.0x Galaxy Li-ion	Galaxy Li-ion is 1.0x to 1.0x BC 2	BC 2 is 0.9x to 1.0x Galaxy Li-ion	BC 2 is 0.7x to 0.7x Galaxy Li-ion	BC 2 is 0.7x to 0.7x Galaxy Li-ion	BC 2 is 2.9x to 2.9x Galaxy Li-ion	BC 2 is 2.6x to 2.7x Galaxy Li-ion
Ozone depletion	kg CFC 11 eq.	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 0.0x Galaxy Li-ion	—	—	—	—	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 0.0x Galaxy Li-ion	Galaxy Li-ion is 29,427.1x BC 2	Galaxy Li-ion is 31,886.4x BC 2
Acidification	Mole H+ eq.	Galaxy Li-ion is 0.4x BC 2	Galaxy Li-ion is 0.4x BC 2	Galaxy Li-ion is 0.4x BC 2	Galaxy Li-ion is 0.4x BC 2	Galaxy Li-ion is 0.2x BC 2	Galaxy Li-ion is 0.2x BC 2	Galaxy Li-ion is 0.8x BC 2	Galaxy Li-ion is 0.9x BC 2	BC 2 is 0.4x Galaxy Li-ion	BC 2 is 0.3x Galaxy Li-ion	Galaxy Li-ion is 0.8x BC 2	Galaxy Li-ion is 0.9x BC 2	BC 2 is 18.3x Galaxy Li-ion	BC 2 is 16.9x Galaxy Li-ion
Eutrophication, freshwater	kg P eq.	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 0.0x Galaxy Li-ion	—	—	—	—	Galaxy Li-ion is 0.4x BC 2	Galaxy Li-ion is 0.4x BC 2	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 3.5x Galaxy Li-ion	BC 2 is 3.2x Galaxy Li-ion
Eutrophication, marine	kg N eq.	BC 2 is 0.5x Galaxy Li-ion	BC 2 is 0.5x Galaxy Li-ion	BC 2 is 0.4x Galaxy Li-ion	BC 2 is 0.3x Galaxy Li-ion	Galaxy Li-ion is 0.2x BC 2	Galaxy Li-ion is 0.2x BC 2	Galaxy Li-ion is 0.5x BC 2	Galaxy Li-ion is 0.5x BC 2	BC 2 is 0.8x Galaxy Li-ion	BC 2 is 0.7x Galaxy Li-ion	Galaxy Li-ion is 0.5x BC 2	Galaxy Li-ion is 0.5x BC 2	BC 2 is 4.2x Galaxy Li-ion	BC 2 is 3.9x Galaxy Li-ion
Eutrophication, terrestrial	Mole of N eq.	BC 2 is 0.7x Galaxy Li-ion	BC 2 is 0.7x Galaxy Li-ion	BC 2 is 0.6x Galaxy Li-ion	BC 2 is 0.5x Galaxy Li-ion	Galaxy Li-ion is 0.2x BC 2	Galaxy Li-ion is 0.2x BC 2	Galaxy Li-ion is 0.9x BC 2	Galaxy Li-ion is 1.0x BC 2	BC 2 is 0.7x Galaxy Li-ion	BC 2 is 0.6x Galaxy Li-ion	Galaxy Li-ion is 0.5x BC 2	Galaxy Li-ion is 0.5x BC 2	BC 2 is 3.8x Galaxy Li-ion	BC 2 is 3.5x Galaxy Li-ion
Photochemical ozone formation, human health	kg NMVOC eq.	BC 2 is 0.8x Galaxy Li-ion	BC 2 is 0.8x Galaxy Li-ion	BC 2 is 0.7x Galaxy Li-ion	BC 2 is 0.7x Galaxy Li-ion	Galaxy Li-ion is 0.2x BC 2	Galaxy Li-ion is 0.2x BC 2	Galaxy Li-ion is 0.5x BC 2	Galaxy Li-ion is 0.6x BC 2	BC 2 is 0.6x Galaxy Li-ion	BC 2 is 0.6x Galaxy Li-ion	Galaxy Li-ion is 0.6x BC 2	Galaxy Li-ion is 0.7x BC 2	BC 2 is 6.3x Galaxy Li-ion	BC 2 is 5.8x Galaxy Li-ion
Resource use, minerals and metals	kg Sb eq.	BC 2 is 1.0x Galaxy Li-ion	BC 2 is 0.9x Galaxy Li-ion	—	BC 2 is 0.9x Galaxy Li-ion	—	—	—	—	—	—	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 1.2x Galaxy Li-ion	BC 2 is 1.1x Galaxy Li-ion
Resource use, fossils	MJ	BC 2 is 0.7x Galaxy Li-ion	BC 2 is 0.7x Galaxy Li-ion	BC 2 is 0.8x Galaxy Li-ion	BC 2 is 0.7x Galaxy Li-ion	Galaxy Li-ion is 0.4x BC 2	Galaxy Li-ion is 0.4x BC 2	Galaxy Li-ion is 0.4x BC 2	Galaxy Li-ion is 0.4x BC 2	BC 2 is 1.0x Galaxy Li-ion	BC 2 is 0.9x Galaxy Li-ion	BC 2 is 0.2x Galaxy Li-ion	BC 2 is 0.2x Galaxy Li-ion	BC 2 is 1.6x Galaxy Li-ion	BC 2 is 1.5x Galaxy Li-ion
Water use	m^3 eq.	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 0.0x Galaxy Li-ion	—	—	—	—	Galaxy Li-ion is 0.1x BC 2	Galaxy Li-ion is 0.1x BC 2	BC 2 is 0.3x Galaxy Li-ion	BC 2 is 0.2x Galaxy Li-ion	BC 2 is 1.2x Galaxy Li-ion	BC 2 is 1.1x Galaxy Li-ion

Table 23 Comparison summary of inventory flows indicators.

Inventory Flow Indicator	Unit	Total (excl. Module D)		Manufacturing (A1-A3)		Distribution (A4)		Installation (A5)		Utilization (B1-B7)		End of Life (C1-C4)		Benefits and Loads (D)	
		Functional unit	Per kWh	Functional unit	Per kWh	Functional unit	Per kWh	Functional unit	Per kWh	Functional unit	Per kWh	Functional unit	Per kWh	Functional unit	Per kWh
Use of renewable primary energy (PERE)	MJ	BC 2 is 6.3x Galaxy Li-ion	BC 2 is 5.9x Galaxy Li-ion	BC 2 is 5.8x Galaxy Li-ion	BC 2 is 5.3x Galaxy Li-ion	BC 2 is 82.5x Galaxy Li-ion	BC 2 is 76.2x Galaxy Li-ion	—	—	BC 2 is 5.6x Galaxy Li-ion	BC 2 is 5.2x Galaxy Li-ion	BC 2 is 56.0x Galaxy Li-ion	BC 2 is 51.7x Galaxy Li-ion	BC 2 is 24.9x Galaxy Li-ion	BC 2 is 23.0x Galaxy Li-ion
Primary energy resources used as raw materials (PERM)	MJ	Galaxy Li-ion is 5.6x BC 2	Galaxy Li-ion is 6.1x BC 2	BC 2 is 1.1x Galaxy Li-ion	BC 2 is 1.0x Galaxy Li-ion	—	—	—	—	—	—	—	—	—	—
Total use of renewable primary energy resources (PERT)	MJ	BC 2 is 5.7x Galaxy Li-ion	BC 2 is 5.2x Galaxy Li-ion	BC 2 is 4.9x Galaxy Li-ion	BC 2 is 4.5x Galaxy Li-ion	BC 2 is 82.5x Galaxy Li-ion	BC 2 is 76.2x Galaxy Li-ion	—	—	BC 2 is 5.6x Galaxy Li-ion	BC 2 is 5.2x Galaxy Li-ion	BC 2 is 56.0x Galaxy Li-ion	BC 2 is 51.7x Galaxy Li-ion	BC 2 is 24.9x Galaxy Li-ion	BC 2 is 23.0x Galaxy Li-ion
Use of non-renewable primary energy (PENRE)	MJ	BC 2 is 0.7x Galaxy Li-ion	BC 2 is 0.6x Galaxy Li-ion	BC 2 is 0.8x Galaxy Li-ion	BC 2 is 0.7x Galaxy Li-ion	Galaxy Li-ion is 0.4x BC 2	Galaxy Li-ion is 0.4x BC 2	Galaxy Li-ion is 0.3x BC 2	Galaxy Li-ion is 0.4x BC 2	BC 2 is 1.0x Galaxy Li-ion	BC 2 is 0.9x Galaxy Li-ion	BC 2 is 0.2x Galaxy Li-ion	BC 2 is 0.2x Galaxy Li-ion	BC 2 is 1.6x Galaxy Li-ion	BC 2 is 1.5x Galaxy Li-ion
Non-renewable primary energy resources used as raw materials (PENRM)	MJ	Galaxy Li-ion is 0.6x BC 2	Galaxy Li-ion is 0.7x BC 2	Galaxy Li-ion is 0.6x BC 2	Galaxy Li-ion is 0.7x BC 2	—	—	—	—	—	—	—	—	—	—
Total use of non-renewable primary energy resources (PENRT)	MJ	BC 2 is 0.7x Galaxy Li-ion	BC 2 is 0.7x Galaxy Li-ion	BC 2 is 0.8x Galaxy Li-ion	BC 2 is 0.7x Galaxy Li-ion	Galaxy Li-ion is 0.4x BC 2	Galaxy Li-ion is 0.4x BC 2	Galaxy Li-ion is 0.4x BC 2	Galaxy Li-ion is 0.4x BC 2	BC 2 is 1.0x Galaxy Li-ion	BC 2 is 0.9x Galaxy Li-ion	BC 2 is 0.2x Galaxy Li-ion	BC 2 is 0.2x Galaxy Li-ion	BC 2 is 1.6x Galaxy Li-ion	BC 2 is 1.5x Galaxy Li-ion
Use of net fresh water (FW)	m^3	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 0.0x Galaxy Li-ion	—	—	—	—	Galaxy Li-ion is 0.1x BC 2	Galaxy Li-ion is 0.1x BC 2	BC 2 is 0.5x Galaxy Li-ion	BC 2 is 0.4x Galaxy Li-ion	BC 2 is 1.9x Galaxy Li-ion	BC 2 is 1.8x Galaxy Li-ion
Hazardous waste disposed (HWD)	kg	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 0.0x Galaxy Li-ion	—	—	—	—	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 0.0x Galaxy Li-ion	BC 2 is 0.0x Galaxy Li-ion	Galaxy Li-ion is 2,624,821,683.3x BC 2	Galaxy Li-ion is 2,844,187,184.2x BC 2
Non-hazardous waste disposed (NHWD)	kg	BC 2 is 0.3x Galaxy Li-ion	BC 2 is 0.2x Galaxy Li-ion	BC 2 is 0.2x Galaxy Li-ion	BC 2 is 0.2x Galaxy Li-ion	BC 2 is 0.1x Galaxy Li-ion	BC 2 is 0.1x Galaxy Li-ion	BC 2 is 0.6x Galaxy Li-ion	BC 2 is 0.5x Galaxy Li-ion	BC 2 is 0.1x Galaxy Li-ion	BC 2 is 0.1x Galaxy Li-ion	Galaxy Li-ion is 0.1x BC 2	Galaxy Li-ion is 0.1x BC 2	BC 2 is 1.1x Galaxy Li-ion	BC 2 is 1.0x Galaxy Li-ion
Radioactive waste disposed (RWD)	kg	Galaxy Li-ion is 0.8x BC 2	Galaxy Li-ion is 0.8x BC 2	BC 2 is 0.5x Galaxy Li-ion	BC 2 is 0.5x Galaxy Li-ion	Galaxy Li-ion is 0.3x BC 2	Galaxy Li-ion is 0.3x BC 2	Galaxy Li-ion is 0.2x BC 2	Galaxy Li-ion is 0.2x BC 2	Galaxy Li-ion is 0.0x BC 2	Galaxy Li-ion is 0.0x BC 2	Galaxy Li-ion is 0.0x BC 2	Galaxy Li-ion is 0.0x BC 2	BC 2 is 3.7x Galaxy Li-ion	BC 2 is 3.4x Galaxy Li-ion
Materials for recycling (MFR)	kg	BC 2 is 2.7x Galaxy Li-ion	BC 2 is 2.5x Galaxy Li-ion	BC 2 is 2.8x Galaxy Li-ion	BC 2 is 2.6x Galaxy Li-ion	—	—	—	—	—	—	BC 2 is 2.7x Galaxy Li-ion	BC 2 is 2.5x Galaxy Li-ion	—	—

Annex

Functional unit normalization

This study normalizes the BC 2 functional unit from power rating (kW for a defined duration in minutes) to backup power capacity (kWh), consistent with the Galaxy Li-ion functional unit definition, while retaining the same reference service life in accordance with *PSR Section 3.15.1.2.*

Available Electrical Data:

	BC 2 (ZF-38A6BS022KB1UF000)[8]	Galaxy Li-ion (LIBSESMG17UL)[9]
Nominal Capacity	>80 Ah C/2	67 Ah**
Nominal Energy	38 kWh (38s) C/2*	34.6 kWh**
Nominal Voltage	494 Vdc (38s)*	517**

Derived Data:
ZF-38A6BS022KB1UF000 has a nominal energy[10] (kWh) of 38 kWh at C/2. To enable fair comparison, we derive the C rate for the available electrical data of the Galaxy Li-ion reference product.
C Rate for nominal energy (LIBSESMG17UL):

$$Discharge\ time\ (hours) = \frac{1}{C_{rate}} = \frac{Nominal\ Energy}{Nominal\ Voltage * Nominal\ Capacity}$$

$$Discharge\ time\ (hours) = \frac{34.6kWh * 1000}{517V * 67Ah} \approx 1\ hour$$

$$C_{rate} = 1C$$

Nominal Energy at 1C (ZF-38A6BS022KB1UF000):
To determine the normalized functional unit for model ZF-38A6BS022KB1UF000, the nominal energy at 1C discharge rate is required. A Constant Current Discharge test (80 A) was performed from 100% State of Charge (SOC) to the Lower Voltage Cut-Off (11 V/battery; 418 V for a 38-battery string) using an Arbin Model RBT3206 Battery Cycler. Results from six Device Under Test (DUT) are presented below.

	DUT 1	DUT 2	DUT 3	DUT 4	DUT 5	DUT 6
Capacity at 1C (Ah)	79.0	80.5	79.6	81.3	80.1	79.2

The mean discharge capacity is 79.95 Ah with a sample standard deviation of 0.86 Ah. A nominal capacity of 79.09 Ah (mean − 1σ) is used. Nominal energy at 1C is then calculated by scaling nominal energy at C/2 proportionally.

$$Nominal\ Energy_{1C} = Nominal\ Energy_{C/2} * \frac{Nominal\ Capacity_{1C}}{Nominal\ Capacity_{C/2}}$$

$$Nominal\ Energy_{1C} = 38kWh * \frac{79.09\ Ah}{80\ Ah} \approx 37.6\ kWh$$

Therefore, the normalized functional unit for the BC 2 reference product is a backup power capacity of 37.6 kWh.

[8] Sourced from BC Series UPS Battery Cabinets Data Sheet. In: BC Series UPS Battery Cabinets Product Documentation. Available at: https://zincfive.com/products/bc-series-ups-battery-cabinets/ → BC → Data Sheet
[9] Sourced from Galaxy Li-ion Battery Cabinet GVX UL Technical Drawing — LIBSESMGGVXUL (v1.3). In: LIBSESMG17UL Product Documentation. Available at: https://www.se.com/us/en/product/LIBSESMG17UL/galaxy-lithiumion-battery-cabinet-ul-with-17-x-2-04-kwh-battery-modules/ → Documents tab
[10] Nominal energy (kWh) is referred to as backup power capacity in the functional unit for Galaxy Li-ion and consequently in the normalized functional unit in this study.

References

ZincFive LLC (2024) *BC 2 UPS Battery Cabinet Product Environmental Profile*. Registration No. Z5BC-00101-V01.01-EN. Verified by VH42. Portland, OR: ZincFive LLC. Available at: www.pep-ecopassport.org

Schneider Electric (2024) *Galaxy Lithium-ion Battery Cabinet Product Environmental Profile*. Registration No. SCHN-01206-V01.01-EN. Verified by VH08. Rueil-Malmaison: Schneider Electric. Available at: www.pep-ecopassport.org

PEP Ecopassport Association (2023) *Product-Specific Rules for Electrical Switchgear and Controlgear Solutions — Other Equipment Family*. PSR-0005-ed3.1-EN-2023 12 08. Paris: PEP Ecopassport Association.

PEP Ecopassport Association (2021) *Product Category Rules for Electrical, Electronic and HVAC-R Products*. PEP-PCR-ed4-EN-2021 09 06. Paris: PEP Ecopassport Association.

International Organisation for Standardisation (2006) *ISO 14044:2006: Environmental management — Life cycle assessment — Requirements and guidelines*. Geneva: ISO.

International Organisation for Standardisation (2006) *ISO 14040:2006: Environmental management — Life cycle assessment — Principles and framework*. Geneva: ISO.

International Organisation for Standardisation (2006) *ISO 14025:2006: Environmental labels and declarations — Type III environmental declarations — Principles and procedures*. Geneva: ISO.

European Committee for Standardisation (2019) *EN 50693:2019: Product category rules for life cycle assessments of electronic and electrical products and systems*. Brussels: CEN.

European Committee for Standardisation (2019) *EN 15804:2012+A2:2019: Sustainability of construction works — Environmental product declarations — Core rules for the product category of construction products*. Brussels: CEN.

Andreasi Bassi, S., Biganzoli, F., Ferrara, N., Amadei, A., Valente, A., Sala, S. and Ardente, F. (2023) *Updated characterisation and normalisation factors for the Environmental Footprint 3.1 method*. JRC Technical Report EUR 31414 EN. Luxembourg: Publications Office of the European Union. doi:10.2760/798894, JRC130796. Available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC130796