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**Integration of additive manufacturing into conventional production for
aluminium body-in-white components — Guidelines for environmental
and economic assessment**

CCMC will prepare and attach the official title page.

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Foreword

This CEN Workshop Agreement (CWA XXXX:YYYY) has been developed in accordance with the CEN-CENELEC Guide 29 “CEN/CENELEC Workshop Agreements – A rapid way to standardization” and with the relevant provisions of CEN/CENELEC Internal Regulations - Part 2. It was approved by the Workshop CEN “Integration of additive manufacturing into conventional production for aluminium body-in-white components”, the secretariat of which is held by “UNE- Spanish association for standardization” consisting of representatives of interested parties on YYYY-MM-DD, the constitution of which was supported by CEN following the public call for participation made on 2026-08-20. However, this CEN Workshop Agreement does not necessarily include all relevant stakeholders.

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Introduction

This document provides methodological principles and requirements for performing an integrated environmental and economic assessment of hybrid manufacturing routes for aluminium Body-in-White (BIW) components, which combine conventional manufacturing processes with additive manufacturing (AM) technologies.

Directed Energy Deposition by means of Laser Beam (DED/LB) additive manufacturing (AM) is increasingly explored as a means of locally reinforcing aluminium components in automotive BIW structures, alongside the conventional manufacturing routes (e.g. extrusion, casting, forming) already established for these components. This hybrid integration of AM into conventional production offers a route to improve structural performance, and enables the lightweighting of components while preserving their structural performance through local, targeted reinforcement.

Beyond the performance benefits enabled by the integration of DED/LB hybrid AM, the adoption of this process depends on the quantification and assessment of its environmental and economic impacts in comparison with the conventional manufacturing process and an alternative DED/LB configuration. In the absence of a shared method, organizations exploring this technology tend to develop their own environmental and economic assessment approaches independently, using different system boundaries, functional units, and data-quality assumptions. This makes it difficult to compare results across studies, to build a reliable evidence base for the technology, or to have confidence that a favourable assessment reflects a genuine improvement rather than a difference in methodological choices.

This document responds to this lack of harmonised methodologies by adapting the general principles of existing Life Cycle Assessment (LCA) standards — specifically the framework defined in ISO 14040 and ISO 14044 — to the specific characteristics of combined additive and conventional aluminium production processes. It specifies a joint environmental and economic assessment methodology for the integration of DED/LB additive manufacturing into conventional production routes for aluminium Body-in-White (BIW) components of automotive vehicles, applicable to systems of any scale, from a single reinforced component up to a complete BIW. The methodology defines the phases to be followed — goal and scope definition, life cycle inventory construction (including a modular, parametric approach), life cycle impact assessment, and interpretation — extended with a parallel economic sustainability assessment that shares the same system model, functional unit, and system boundaries. It supports comparison of the assessed system against a conventional manufacturing route or against an alternative DED/LB configuration differing in geometry, process parameters, or substrate, and is designed to be applied consistently across different process configurations, component geometries, and levels of data availability — including at early technology readiness levels, where detailed industrial data may not yet exist.

The future benefit of this document lies in enabling manufacturers, technology providers, and research organizations to compare the environmental and economic performance of different hybrid manufacturing configurations on a consistent basis, to identify where in the process chain the greatest environmental or economic gains can be achieved, and to support the environmental re-design (ecodesign) of vehicle components from early development stages.

1 Scope

This document specifies the methodological principles and requirements for performing an integrated environmental and economic assessment of hybrid manufacturing routes that combine conventional manufacturing processes with Directed Energy Deposition / Laser Beam (DED/LB) additive manufacturing technologies.

The methodology applies to the integration of DED/LB additive manufacturing processes into conventional production lines for metallic body-in-white (BIW) components of road vehicles.

This document is applicable to metallic BIW components manufactured through hybrid manufacturing configurations integrating additive and conventional production processes. This document provides sector-specific and application-oriented methodological guidance for the assessment of hybrid manufacturing in the automotive body-in-white context.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14040:2006, *Environmental management — Life cycle assessment — Principles and framework*

ISO 14044:2006, *Environmental management — Life cycle assessment — Requirements and guidelines*

ISO/ASTM 52900, *Additive manufacturing — General principles — Fundamentals and vocabulary*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at <http://www.iso.org/obp/>

— IEC Electropedia: available at <http://www.electropedia.org/>

3.1

body-in-white

BIW

welded (or otherwise joined) structural sheet metal and structural components of an automotive vehicle, assembled prior to painting and before the addition of moving parts, closures, powertrain, chassis sub-assemblies, and trim

3.2

DED/LB process

directed energy deposition additive manufacturing process using a laser beam as the energy source, in which focused thermal energy is used to fuse materials by melting as they are deposited

[SOURCE: ISO/ASTM 52900]

3.3

hybrid manufacturing

combination of an additive manufacturing process and one or more conventional manufacturing processes within a single production route for a component

3.4

extent of the assessed system

scale at which the system being assessed by this methodology is defined, ranging from a single hybrid-manufactured component up to a complete BIW

3.5

functional unit

quantified performance of a product system for use as a reference unit

[SOURCE: ISO 14040:2006]

3.6

configuration

specific combination of geometry, process parameters, equipment, and/or substrate that defines a particular application of a DED/LB process to a given component or assembly

3.7

baseline

reference configuration against which the assessed system is compared; a baseline may be a conventional manufacturing route not incorporating a DED/LB process, or an alternative hybrid-manufactured configuration

3.8

primary data

data directly measured or recorded for the specific process under investigation

3.9

processed data

data derived from primary data through parameterised process calculations or material-balance relationships

3.10

secondary data

data derived from a source other than direct measurement of, or calculation from, the specific process under investigation, such as peer-reviewed literature, recognized databases, supplier specifications, technical reports, or industrial benchmarks

3.11

economic sustainability assessment

assessment of the economic performance of a product system over its life cycle, conducted in parallel with, and sharing the system definition of, a life cycle assessment

3.12

mass-sensitivity coefficient

coefficient expressing the change in use-phase energy or fuel consumption of a vehicle per unit change in mass and per unit distance travelled

3.13

ecodesign

integration of environmental aspects into product design and development, with the aim of reducing adverse environmental impacts throughout the life cycle of a product

4 Methodology

4.1 General principles

This document defines a joint environmental and economic assessment methodology for evaluating the integration of DED/LB additive manufacturing into conventional production routes for aluminium BIW components of automotive vehicles. The methodology follows the four iterative and interconnected phases defined in ISO 14040 for LCA (Goal and Scope Definition, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA), and Interpretation) and extends this structure to a parallel economic sustainability assessment, so that the environmental and economic evaluations share the same system model, functional unit(s), and system boundaries.

Two independent dimensions structure the application of this methodology: the extent of the assessed system, which is a question of scale (e.g. a single component versus a complete BIW), and the configuration of the assessed system, which is a question of design (e.g. differing geometry, process parameters, or substrate). Either dimension may be varied independently of the other, although the comparative nature of the assessment requires that some parameters remain consistent between compared systems. Specifics are described in the relative sections of this document.

4.2 Goal and scope definition

4.2.1 Purpose and audience

The goal and scope definition phase establishes the purpose of the assessment, including its intended application, target audience, and the decisions it is intended to inform. In a generic LCA study, each of the following choices is typically made independently for each application; this document standardizes the key methodological choices — functional unit, system boundaries, allocation procedures, and underlying assumptions needed to model the hybrid manufacturing system under evaluation, as specified in 4.2.2 to 4.2.9, so that these choices need not be redefined case by case and results remain comparable across different applications of this methodology.

4.2.2 Extent of the assessed system

This methodology applies to an aluminium body-in-white (BIW) system incorporating a DED/LB process, at any extent of that system — from a single AM-integrated component, through a sub-assembly, up to a complete assembly (the whole BIW). The extent of the assessed system is a scoping choice made in accordance with the goal of the assessment (see 4.2.1) and shall be explicitly stated; the same methodology defined in this document applies at every extent, and no alternative or different assessment method is defined for any one extent. Moving from a single component to a larger assembly composed of multiple such components is achieved through the modular structure of the life cycle inventory (see 4.3.2 and 4.3.5), which allows the unit processes developed for one component to be aggregated to represent a larger system without requiring a different assessment method.

4.2.3 Functional units and reference flows

A functional unit shall be defined as one component, sub-system, or BIW fulfilling case-specific structural and safety performance requirements, over the defined reference service life and under the assumed operating conditions. The structural and safety performance requirements, reference service life and operating conditions shall be defined case-by-case, in accordance with the goal and scope of the specific assessment (see 4.2.1). Where the methodology is applied at more than one extent within the same study (e.g. to a component and to the assembly that contains it), a functional unit shall be defined for each extent considered, and the relationship between them shall be documented to ensure consistency between the two.

4.2.4 System boundaries

A cradle-to-grave system boundary shall be adopted as the default for the assessed system, at whatever extent it is defined, encompassing raw material extraction, manufacturing, distribution, use phase, and end-of-life treatment. This applies equally to a single component and to a full assembled BIW: distribution, use-phase and end-of-life stages shall be modelled as attributable to the assessed system in proportion to its contribution to the larger system in which it functions (e.g. via its mass contribution), even where the assessed system is a single isolated component.

The system boundary may be restricted — for example, by ending the assessment at the factory gate (cradle-to-gate), or by excluding specific life cycle stages or processes — where this is justified by the goal and scope of the specific assessment. Acceptable justifications include, but are not limited to: the excluded stage(s) or process(es) can be demonstrated or reasonably assumed to have a negligible contribution to the overall environmental or economic impact; or the excluded stage(s) fall outside the scope of the specific assessment (e.g. an early-stage component-level screening not intended to capture use-phase or end-of-life effects). Any restriction of the system boundary shall be explicitly stated and justified, and its potential effect on the completeness and comparability of the results shall be discussed.

The foreground system shall include the hybrid manufacturing processes under evaluation, while the background system shall comprise upstream and downstream processes modelled using secondary data (e.g. material production, energy supply, waste treatment). Infrastructure (e.g. production equipment and tooling) may be excluded where its contribution is expected to be minor, provided this assumption is justified and referenced.

4.2.5 Comparative modelling approach

Where the assessed system is compared against a baseline, whether a conventional manufacturing route or an alternative DED/LB-integrated configuration, a comparative modelling approach shall be adopted: processes and life cycle stages that are identical in both systems may be excluded from detailed modelling, provided this simplification is justified and a completeness check is performed to confirm that the cumulative contribution of excluded processes does not significantly affect the conclusions. The assessment shall focus on the processes and parameters that differ qualitatively or quantitatively between the systems (e.g. material composition, geometry, process parameters, manufacturing route, mass-related use-phase effects).

4.2.6 Cut-off criteria

Cut-off criteria shall be applied to exclude flows considered negligible in terms of mass, energy, and environmental or economic relevance. Flows representing less than 1% of total mass, energy, or environmental/economic relevance may be excluded, provided that the cumulative excluded flows do not exceed 5% against any of these criteria. DED/LB reinforcement typically introduces a mass that is small relative to the component as a whole: in some cases only a few percent of the total mass, and occasionally below 1%. This mass, and its associated input and output flows, shall not be excluded on cut-off grounds regardless of its share of total mass. More generally, no flow shall be excluded, even where individually below the stated thresholds, if its exclusion would misrepresent the hybrid manufacturing technology being assessed, and no environmentally or economically relevant flow shall be intentionally omitted.

4.2.7 Modelling approach and allocation

An attributional LCA approach shall be followed by default, describing the environmental burdens associated with the product system(s) under the defined baseline and assessed configurations.

In accordance with ISO 14044, allocation shall be avoided wherever possible. Whenever a unit process produces multiple co-products or provides multiple functions, process subdivision or system expansion shall be considered first, in order to attribute environmental burdens without resorting to allocation. Where process subdivision or system expansion are not applicable, allocation based on physical relationships (e.g. mass or energy content) shall be used instead. Economic allocation shall be applied only as a last resort, where no physical relationship can be established. Allocation rules shall be applied consistently regardless of the extent of the assessed system.

4.2.8 End-of-life modelling

End-of-life modelling, including recycling of aluminium components, shall be addressed using a defined and documented approach in accordance with ISO 14044, with the implications of this modelling choice evaluated through sensitivity analysis.

4.2.9 Normalization and weighting

Normalization and weighting are optional elements of LCIA and are not required by this methodology. Where the goal and scope of the assessment calls for normalization and weighting of results (for example, to support internal decision-making) these shall be performed in accordance with the general provisions of ISO 14044, and the normalization references and weighting factors used shall be explicitly documented and justified. Weighting shall not be used to support comparative assertions intended to be disclosed to the public, consistent with ISO 14044.

Where normalization and/or weighting are not applied, this exclusion shall be stated, together with the rationale (e.g. to preserve the transparency of category-level results and avoid the value choices necessary for aggregation).

4.3 Life cycle inventory (LCI)

4.3.1 General approach

The LCI phase comprises the systematic collection, quantification, and documentation of all energy and material flows entering and leaving the system, including inputs (materials, auxiliary substances, energy carriers, equipment usage) and outputs (emissions, wastes, co-products, and the final product itself). The LCI shall be developed for each module defined in 4.3.2 and 4.3.5, applying to each the data-use hierarchy defined in 4.3.3 to determine, for every inventory flow, whether primary, processed, or secondary data are used.

4.3.2 Modular and parametric structure

Data collection and inventory modelling shall be structured according to a modular and parametric approach, reflecting the inherently modular, multi-process nature of hybrid manufacturing. Each manufacturing step shall be modelled as an independent unit process (module), with its own inputs, outputs, and performance parameters, defined through analytical relationships based on design and process parameters; these modules are subsequently assembled to represent the complete manufacturing route (see Figure 1 and 4.3.5). A similar modular approach shall be applied for the remaining steps of the life cycle, that shall be considered as independent blocks. This modular structure enables flexibility and transparency in the assessment, facilitates the identification of process-specific environmental and economic hotspots, and supports standardization, scalability, and extrapolation of results to alternative design configurations, geometries, and applications. This modular structure is also what allows the methodology to be applied at different extents of the assessed system (see 4.2.2): the unit processes developed for a single component constitute the building blocks used to represent a larger assembly composed of multiple such components, without requiring a distinct assessment method for each extent.

4.3.3 Data-use hierarchy

A hierarchical data-use strategy shall be adopted to maximise representativeness, consistency, and reliability while addressing risks associated with incomplete industrial datasets. This data-use hierarchy allows a preliminary assessment to be carried out at low technology readiness levels (TRLs): processed data (see below) can be used to estimate the inventory flows of a future, more mature version of the process from parametrised relationships, and to preview its performance at an assumed target scale (e.g. industrial), even where detailed data at that target scale do not yet exist. Three levels of data shall be distinguished and applied in the following order of preference:

- Primary data — directly measured or recorded for the process under investigation.
- Processed data — derived from primary data through parameterised process calculations and material-balance relationships; used where direct measurement is unavailable, or to validate the internal consistency of primary data.
- Secondary data — derived from peer-reviewed literature, recognized databases, supplier specifications, technical reports, or industrial benchmarks; used only where neither primary nor processed data can be obtained, and always documented transparently.

For all data types, including primary data collected at a pilot scale, representativeness for the target conditions defined by the goal and scope of the specific assessment (e.g. industrial-scale operation, where that is the intended target) shall be assessed and, where necessary, adjusted. Data quality shall be assessed against technological, geographical, and temporal representativeness, completeness, consistency, and reliability.

4.3.4 Assumptions and limitations

All assumptions made in constructing the inventory (e.g. scale-up/extrapolation from pilot data, use-phase relationships, reference lifetime and operating conditions) shall be explicitly documented, together with the limitations they introduce, and addressed through sensitivity analysis where relevant.

In particular, a limitation embedded in the presented methodology is that the frontal cross-sectional area of the deposited traces is approximated as the product of hatch spacing and layer thickness. This directly affects the deposition-rate formula modelling the deposition time, given in Table 1 (4.3.5(b)). This is a reasonable approximation across most practical combinations of hatch spacing and track width.

4.3.5 LCI methodology by life cycle stage

This subclause defines, for each production module listed below, the general approach to be used to construct its life cycle inventory. A DED/LB-integrated aluminium BIW component or assembly shall be decomposed into the applicable modules from among the following:

a) Base component / substrate production. The conventional manufacturing route (e.g. extrusion, casting, forming, joining) producing the component onto which the DED/LB process is applied. This module, and the methodology as a whole, applies regardless of the specific aluminium alloy, shape, or conventional manufacturing process used for the substrate. The LCI of this module shall be constructed using the data-use hierarchy defined in 4.3.3, drawing on primary data from the relevant manufacturing process where available, supplemented as needed by processed or secondary data.

b) DED/LB process. The additive deposition operation itself. The LCI of this module shall be constructed following a parametric approach: each inventory flow (e.g. feedstock consumption, shielding gas consumption, electricity demand, process duration) shall be expressed as a function of measurable geometry, process, and equipment parameters, of the general form $\text{Flow}_i = f(G, P, M)$, where G denotes parameters related to the geometry of the deposited volume (e.g. dimensions, deposited volume), P denotes parameters related to the process operating conditions (e.g. scan speed, hatch spacing, layer thickness, deposition rate), and M denotes parameters related to the additive manufacturing equipment (e.g. energy source power, cooling system). These parametric relationships shall be validated against directly measured primary data where such data are available (see 4.3.3), and used to estimate missing inventory flows where they are not.

The parametrised LCI of the DED/LB process module (module (b) above) shall be constructed using the mathematical functions given in Table 1, consistent with the general form $\text{Flow}_i = f(G, P, M)$ introduced above. In the 'Description' column, each parameter is annotated as p (primary data), c (processed data), or s (secondary data), and, where relevant, as G (geometry), P (process), or M (equipment), for reference and consistency with the data-use hierarchy (4.3.3) and the parameter classification introduced above.

Table 1 — LCI parametric functions by inventory flow (4.3.5(b))

Inventory flow(s)	Process parameter	Formula	Description
all	Effective deposition time (t_{dep})	$t_{dep} = \frac{V_{dep}}{v_{scan} \times h_{space} \times t_{layer} \times \eta_{dep}}$	Where: V_{dep} is the total reinforcement deposited volume (p, G) v_{scan} is the scan speed (p, P), h_{space} is the hatch spacing (p, G), t_{layer} is the layer thickness (p, G) t_{dep} is the deposition efficiency, meaning the percentage of deposited powder on the total spent powder (p, P) Effective deposition time is calculated as the total reinforcement volume to be deposited divided by the volumetric deposition rate of the process. The theoretical component of this rate is given by the scan speed multiplied by the cross-sectional area swept by the beam in a single pass, the latter approximated as hatch spacing multiplied by layer thickness. However, not all of the material supplied to the process is incorporated into the deposited trace, owing to process inefficiencies and powder losses inherent to the deposition mechanism; a deposition efficiency factor is therefore applied to correct the theoretical volumetric deposition rate down to the rate of material actually and effectively deposited.

Inventory flow(s)	Process parameter	Formula	Description
Energy input	Total process energy consumption (E_{tot})	$E_{tot} = P_{avg} \times t_{dep} + P_{aux} \times t_{rest}$	Where: P_{avg} is the average process power, combining the power of the laser and the auxiliary power consumption, including laser operation, powder feeder, motion system, cooling system, control electronics (p/s, M) P_{aux} is the auxiliary power consumption only (p/s, M) t_{rest} is the time of resting of the machine, where no laser deposition takes place (p/s, G) Total energy consumption is calculated as a function of machining and auxiliary power and total deposition time (comprising resting from deposition).
Material input (powder)	Powder mass used ($m_{p,input}$)	$m_{p,input} = m_{r,p} \times t_{dep}$	Where: $m_{r,p}$ is the powder feed rate (p, P) The powder mass input is calculated as a function of powder feed rate and effective deposition time. This input has to be further modelled as a sum of virgin powder and secondary powder that is recirculated in the system, following a reuse rate.
Material input (shielding gas)	Shielding gas volume used ($V_{gas,input}$)	$V_{gas,input} = V_{r,gas} \times (t_{dep} + t_{rest})$	Where: $V_{r,gas}$ is the shielding gas volumetric feed rate (p, P)
Material output (powder)	Powder mass waste ($m_{p,res}$)	$m_{p,res} = m_{p,input} - m_{p,dep} - m_{p,reuse}$	Where: $m_{p,dep}$ is the mass of powder effectively deposited (c, P) $m_{p,reuse}$ is the mass of non-deposited mass that is reused in the process (c, P).

c) Post-processing. Any treatment applied to the deposited material or component after deposition (e.g. thermal treatment, machining, surface finishing), included only where applicable to the specific case being assessed. Each post-processing operation shall be modelled as its own unit process, following the same parametric approach as module (b), with its own dedicated inventory and background datasets.

d) Distribution. Transport flows shall be modelled in accordance with the relevant provisions of ISO 14044.

e) Use phase. Included where the system boundary defined in 4.2.4 is not restricted to exclude it. DED/LB-based modifications to a component commonly result in a change in its mass relative to the baseline, whether an increase or a decrease, which in turn affects the use-phase energy or fuel consumption of the larger system in which the component operates. Use-phase flows shall be modelled using the mathematical function given in Table 3.

Table 3 — Use-phase energy or fuel consumption change (4.3.5(e))

Inventory flow(s)	Process parameter	Formula	Description
Use phase	Use-phase energy or fuel consumption change (ΔE_{use})	$\Delta E_{\text{use}} = \Delta m \times k_m \times D$	Where: Δm is the difference in mass (kg) between the assessed system and the baseline k_m is a mass-sensitivity coefficient, expressing the change in use-phase energy or fuel consumption per unit mass change and per unit distance travelled, appropriate to the powertrain type of the system in which the component operates (e.g. expressed in L/100 km per 100 kg for an internal combustion powertrain, or kWh/100 km per 100 kg for a battery-electric powertrain) D is the reference distance travelled over the service life defined in 4.2.3 The value of k_m shall be sourced from published automotive LCA literature or from powertrain-specific data, and the source referenced.

f) End-of-life and recycling. Included where the system boundary defined in 4.2.4 is not restricted to exclude it, modelled in accordance with the end-of-life approach selected under 4.2.8, and covering both the base component material and any additively deposited material.

The applicable modules, and the way in which they are assembled, depend on the extent of the assessed system (4.2.2) and the system boundary adopted (4.2.4): a cradle-to-gate component-level assessment will typically combine modules (a) to (c), while a full cradle-to-grave assessment of a component or of a complete BIW will combine modules (a) to (f), with modules (b) and, where relevant, (c) instantiated once per DED/LB-reinforced location and aggregated accordingly. Figure 1 illustrates this modular structure.

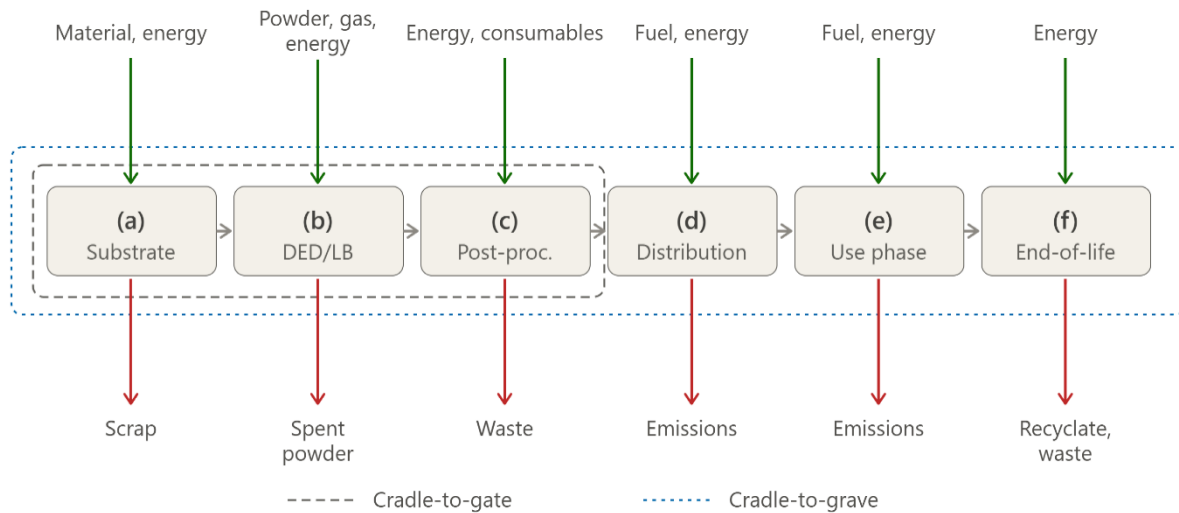


Figure 1 — Modular structure of the life cycle inventory, with input/output flows and system boundaries

4.4 Life cycle impact assessment (LCIA)

The LCIA phase translates inventory data into potential environmental impacts by applying a characterization model across selected impact categories. The impact assessment method(s) used shall be explicitly named (e.g. Environmental Footprint 3.1, ReCiPe), together with the rationale for their selection and the implications of this choice for the results. This step identifies which life cycle stages or processes contribute most to environmental impacts and where improvement opportunities exist. The decision on whether to apply normalization and/or weighting to the results, and the associated disclosure requirements, are addressed in 4.2.9.

4.5 Economic sustainability assessment

4.5.1 General approach

In parallel with the LCA, an economic sustainability assessment shall be conducted using the same system definition(s) and functional unit(s) defined for the assessed system (see 4.2.2–4.2.3). On the basis of the system boundary defined, the economic sustainability assessment shall include cost categories related to material production, manufacturing, distribution, use-phase energy consumption, end-of-life treatment, and, where relevant, labour-related costs not captured in the LCA. Assumptions regarding cost parameters and system lifetime shall be aligned with the LCA framework to ensure consistency between the environmental and economic assessments.

4.5.2 Modular and parametric cost model

The economic sustainability assessment shall mirror the modular and parametric structure adopted for the LCI (see 4.3.2 and 4.3.5), with cost elements expressed as functions of the same measurable process parameters and design/geometry variables, in order to ensure methodological consistency and transferability between the environmental and economic assessments. The same three-level data-use hierarchy defined in 4.3.3 (primary, processed, secondary) shall apply to economic and operational data.

4.5.3 Economic data collection approach

This subclause defines the general approach to collecting and structuring economic data for each production module defined in 4.3.5, mirroring the environmental LCI structure.

For each module, cost elements shall be identified covering, as applicable: material and feedstock costs, energy costs, labour costs, machine/equipment operation and maintenance costs, and consumables. Cost elements associated with the DED/LB process module and with the post-processing module (see 4.3.5(b) and (c)) shall be expressed as parametric functions of the same geometry, process, and equipment parameters (G, P, M) used for the corresponding LCI flows, in order to preserve consistency and transferability between the environmental and economic assessments (see 4.5.2).

The economic assessment of the DED/LB process module shall be modelled using the mathematical functions given in Table 2, mirroring the parametric structure of Table 1 (4.3.5). In the 'Description' column, cost parameters are annotated using the same p, c, s, G, P, and M labels defined above, plus N where a parameter is external to the manufacturing process itself (e.g. electricity prices, material prices, labour rates). Primary cost and operational data shall be prioritised, collected directly from the relevant manufacturing partner or process owner, following the data-use hierarchy defined in 4.3.3.

Table 2 — Economic assessment parametric functions by cost element (4.5.3)

Cost voice	Formula	Description
Total manufacturing cost (C_{tot})	$C_{tot} = C_{material} + C_{energy} + C_{gas} + C_{machine} + C_{labour} + C_{maintainance} + C_{post-process}$	The total manufacturing cost was modelled as the sum of material costs ($C_{material}$), electricity consumption (C_{energy}), shielding gas use (C_{gas}), labour (C_{labour}), machine operation ($C_{machine}$), maintenance ($C_{maintainance}$), and post-processing activities ($C_{post-process}$).
Material costs (powder)	$C_{material} = m_{vir} \times c_{vir} + m_{reuse} \times c_{reuse}$	Where: m_{vir} and m_{reuse} are the virgin powder demand and the secondary powder use, respectively (p, P); c_{vir} and c_{reuse} are the virgin powder unit cost and the reused powder processing cost, respectively (p/s, N). Material costs were calculated based on powder consumption and unit powder price, accounting for deposition efficiency and powder reuse whenever applicable, and therefore considering the unit costs of both virgin and recycled powder.
Electricity consumption costs (C_{energy})	$C_{energy} = E_{tot} \times c_{electricity}$	Electricity costs were derived from the total process energy demand (E_{tot} – c, M, P) and the corresponding industrial electricity price ($c_{electricity}$ – p/s, N).
Post-processing costs ($C_{post-process}$)	$C_{post-process} = \sum_i C_{pp,i}$	Post-processing costs are modelled as the sum of the individual post-processing operations applied to the reinforced component ($C_{pp,i}$).

Cost voice	Formula	Description
Remaining cost voices (namely C_{gas} , $C_{machine}$, C_{labour} , $C_{maintenance}$)	$C_x = (t_{dep} + t_{rest}) \times c_x$	Where: C_x represents the cost contribution of a given process activity, t_{dep} is the effective deposition time (c, G/P), t_{rest} is the time of resting of the machine, where no laser deposition takes place (p/s, G) c_x is the corresponding time-dependent unit cost (€/h – p/s, N). Modelled as functions of the effective deposition time and resting time.

4.6 Interpretation and comparability

4.6.1 Interpretation

The interpretation phase synthesizes the results of the LCI, LCIA, and the economic sustainability assessment, evaluating them against the defined goal and scope. It shall identify the key drivers of environmental and economic impacts, assess uncertainties, and include sensitivity or scenario analyses, performed in accordance with ISO 14044. Results shall be interpreted relative to the defined baseline to clarify whether, where, and how the assessed configuration delivers advantages or introduces trade-offs relative to that baseline.

4.6.2 Comparability and consistency

All methodological choices — system boundaries, allocation rules, data sources, and modelling assumptions — shall be applied consistently across all extents at which the assessed system is analysed, across all configurations or baselines being compared, and between the LCA and the economic sustainability assessment, to ensure comparability of results.

4.6.3 Critical review

Where the assessment is intended for internal/consortium use only, this shall be stated, together with confirmation that no comparative assertions are disclosed publicly without an appropriate critical review conducted in accordance with ISO 14040/14044 requirements.

4.7 Reporting requirements

A report documenting the application of this methodology shall include, at a minimum:

- the functional unit(s), the extent of the assessed system, and the system boundaries applied, including any restriction of the cradle-to-grave default and its justification;
- all assumptions and simplifications made, and their justification;
- the impact assessment method(s)/model(s) used;
- results, presented by life cycle stage and/or process module;
- the end-of-life modelling approach selected in accordance with 4.2.8, and the assumptions underlying it; and
- where the assessed system is compared against a baseline or against alternative configurations the parameters varied between them (see 4.3.5) and those held constant.

Bibliography

- [1] Ecoinvent v3.11, *Ecoinvent database*
- [2] European Commission, Joint Research Centre, *Suggestions for updating the Product Environmental Footprint (PEF) method (normalisation and weighting)*, doi:10.2760/88930
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- [4] European Commission, Joint Research Centre, *Environmental Footprint (EF) 3.1 impact assessment method*
- [5] OpenLCA, *OpenLCA life cycle assessment software*