TRANSFORMER IN GRID

Embedded Carbon Declaration on Transformer Nameplates

Towards transparency and accountability in transformer sustainability

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ABSTRACT

Transformer nameplates reveal electrical identity, but not the carbon footprint of the product itself. This article argues for adding an Embedded Carbon Declaration (ECD) that reports cradle-to-gate emissions and links to verified LCA/EPD data via QR code. As grids decarbonize, this metric becomes essential for procurement, Scope 3 accounting, and real sustainability leadership.

KEYWORDS:

embedded carbon, cradle-to-gate assessment, life cycle assessment (LCA), environmental product declaration (EPD), scope 3 emissions, decarbonization

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Introduction

The missing metric on the nameplate

Transformer nameplates have long served as the "identity card" of a power transformer. They tell us about important parameters that an operator needs to know about ratings, impedance, insulation level, cooling method and other details. Yet one vital metric is still missing today: the carbon footprint of the product itself.

As the global power sector races toward net-zero emissions, asset manufacturers are being encouraged to declare not only how efficiently their equipment performs in service, but also how much embedded (embodied) carbon was released during its manufacture.

Embedded carbon represents all greenhouse (Green House Gas - GHG) emissions associated with the materials, processes, and logistics that bring a transformer from raw material to the factory gate. It is distinct from operational carbon, which arises from load and no-load losses during service life. The impact of operational carbon footprint is highlighted in [1].

The proposal to include an Embedded Carbon Declaration (ECD) on transformer nameplates is a natural evolution, linking Life Cycle assessment (LCA) data directly to the product identity. In doing so, it transforms the nameplate from a static compliance tag into a sustainability declaration.

2. Why embedded carbon matters

2.1 Beyond efficiency

For decades, transformer efficiency has been the main sustainability proxy [2]. Manufacturers compete on total losses, and utilities evaluate bids through Loss Capitalization or Total Cost of Ownership (TCO) methods [3]. These focus on operational emissions, the CO_{2e} generated when losses translate into wasted generation over decades of service.

As the grid decarbonises, this equation changes. Renewable and low-carbon generation reduces the emissions associated with operational losses but does nothing to reduce the emissions already "locked in" during manufacturing.

In a conventional grid (e.g., 0.7 $tCO_{2e/MWh}$), a 50 MVA transformer with 275 kW total losses operating continuously over 40 years could indirectly emit ≈21,000 tons of CO_{2e} from energy losses, dwarfing its

manufacturing footprint of approximately 190 tons of CO_{2e}.

However, if that same transformer operates in a future grid averaging 0.05 tCO_{2e}/MWh (typical of renewables-dominated systems such as Tasmania, Australia, or New Zealand), the lifetime operational emissions drop to 1,500 tons of CO_{2e}, which means only 10 times the embedded carbon instead of 120 times under a conventional grid.

In other words, as operational emissions shrink, embedded emissions become a larger share of the total, closing 30-40% of the transformer's full lifecycle footprint by 2040–2050 [4].

This inversion shifts attention from efficiency alone to upstream sustainability:

- When energy is clean, where and how the transformer is built matters as much as how efficiently it runs.
- Procurement teams will need to evaluate embedded carbon intensity ($tCO_{2e/MVA}$) alongside efficiency.
- Manufacturers will face incentives to decarbonize supply chains by adopting recycled copper, green steel, renewable electricity, and low-impact logistics.

As operational emissions shrink, embedded emissions become a larger share of the total, closing 30-40% of the transformer's full lifecycle footprint by 2040–2050

Embedded emissions occur even before the transformer is energized, primarily from:

- Electrical steel production (high-energy smelting and rolling),
- Copper refining and conductor fabrication,
- Core manufacturing – coil slitting, cutting, and assembly,
- Winding manufacturing and drying preparation,
- Active part assembly and drying,
- Mineral or ester fluid processing and filling,
- Tank manufacturing and painting,
- Final assembly, testing & factory acceptance testing,
- Transportation and logistics,
- Site assembly and site acceptance testing.

Reducing these emissions requires

For utilities with net-zero by 2040–2050 targets, the embedded carbon from new equipment purchases will dominate residual Scope 3 emissions

Embedded carbon (sometimes “embodied carbon”) is the sum of all GHG emissions released in producing a product, expressed as tCO_{2e}

supply-chain transparency and material innovation, both of which begin with measurement!

For utilities with net-zero by 2040–2050 targets, the embedded carbon from new equipment purchases will dominate residual Scope 3 emissions. Scope 3 emissions are indirect GHG emissions that occur from a company’s value chain, resulting from activities it doesn’t own or control. These include both upstream activities, like raw material sourcing, and downstream activities like the use and disposal of its products. Even if transformers operate on 100% renewable power, every new installation introduces upfront emissions that must be offset, credited, or reduced at source.

Therefore, declaring and minimizing embedded carbon is not merely good practice, it becomes the principal lever for further decarbonization once the grid itself runs clean. CIGRE Working Group WG A2/C3.70 is working towards a unified framework and recommended best practices.

2.2 Procurement and Scope 3 emissions

Most utilities and renewable developers are now required to report Scope 3 emissions: indirect emissions from purchased goods and services [5]. Transformers, being high-material, long-life assets, make up a significant portion of these upstream Scope 3 categories.

An ECD allows procurement teams to:

- Benchmark suppliers quantitatively.
- Set emission-intensity targets (e.g., $tCO_{2e/MVA}$).
- Reward manufacturers adopting low-carbon steel or recycled copper.
- Integrate carbon metrics alongside efficiency in tender evaluation.

In short, ECD shifts sustainability from corporate reporting to technical specification.

Adding embedded carbon to the nameplate brings environmental transparency to the same level as electrical transparency in terms of losses

3. What is embedded carbon and how is it calculated?

3.1 Definition

Embedded carbon (sometimes “embodied carbon”) is the sum of all GHG emissions released in producing a product, expressed as tCO_{2e}. For transformers, this covers all processes from raw material extraction to factory gate, typically known as cradle-to-gate assessment. This quantification follows established frameworks such as ISO 14044, 14067 Life Cycle Assessment principles [6], [7].

3.2 Typical boundaries

Table 1 lists the typical stages of the “cradle-to-gate” stages of the transformer manufacturing process.

The result is expressed either as total CO_{2e} per transformer or normalized to tCO_{2e} per MVA, enabling fair comparison across sizes.

3.3 From technical data to environmental data

Adding embedded carbon to the nameplate brings environmental transparency to the same level as electrical transparency in terms of losses. A proposed layout (Figure 1) could include a new field within the nameplate data block:

A QR code could point to the transformer’s verified Environmental Product Declaration (EPD), showing the LCA assumptions, boundaries, and emission factors. This could additionally include

Table 1. Main emission stages/sources for embedded carbon in Transformers.

Stage	Description	Main Emission Sources
Raw materials	Steel, copper, insulation, oil	Energy-intensive production, mining
Component manufacturing	Core cutting, coil winding, tank fabrication, painting.	Electricity consumption
Assembly	Drying, vacuum, oil filling	Process energy
Testing and dispatch	Routine test operations	Power draw from test bays
Logistics	Transport to the site or port	Diesel and shipping fuel

estimated operational carbon footprint, recycled material content, and recyclability potential at the end of life of the transformer.

A full sustainability picture also includes the recyclability and recovery potential of transformer materials. Embedded carbon provides a baseline; recycled content and remanufacturing credits reduce it. When transformers are refurbished instead of replaced, the avoided embedded carbon can be quantified and reported, turning sustainability into measurable asset-management value.

3.4 Benefits for stakeholders

There are several benefits to different stakeholders:

- Transformer Original Equipment Manufacturers (OEMs) can demonstrate sustainability leadership and differentiate products.
- Utilities and other end users can account for Scope 3 emissions and select low-carbon options.
- Regulators can track progress toward national or corporate carbon targets.
- End users gain a tangible indicator of lifecycle responsibility.

IEC Technical Committee TC14 and CIGRE Working Group WG A2/C3.70 could play central roles, building on existing eco-design and environmental assessment frameworks

4. Implementation framework

4.1 Standardization needs

For the idea to become practical, harmonized calculations with the new industry standard on the following are required:

- System boundaries: define whether transport to the site is included.
- Functional unit: per transformer or per MVA.
- Data quality: supplier-specific vs. industry-average factors.
- Verification: third-party certification or self-declaration.

Bodies such as IEC Technical Committee TC14 (Power Transformers) and CIGRE Working Group WG A2/C3.70 could play central roles, building on existing eco-design and environmental assessment frameworks. International standards such as ISO 14044 and ISO 14067 are good starting points for formulating these new harmonised calculations. The DNV project titled “Power Transformer Sustainability Practice” has provided good guidance on standardization practices.

4.2 Digital integration

The transition to digital nameplates (e-plates) and asset digital passports supports this concept perfectly. Instead of engraving static data, QR-linked nameplates can hold:

- Complete LCA reports,
- Maintenance and recycling data,
- End-of-life material recovery information.

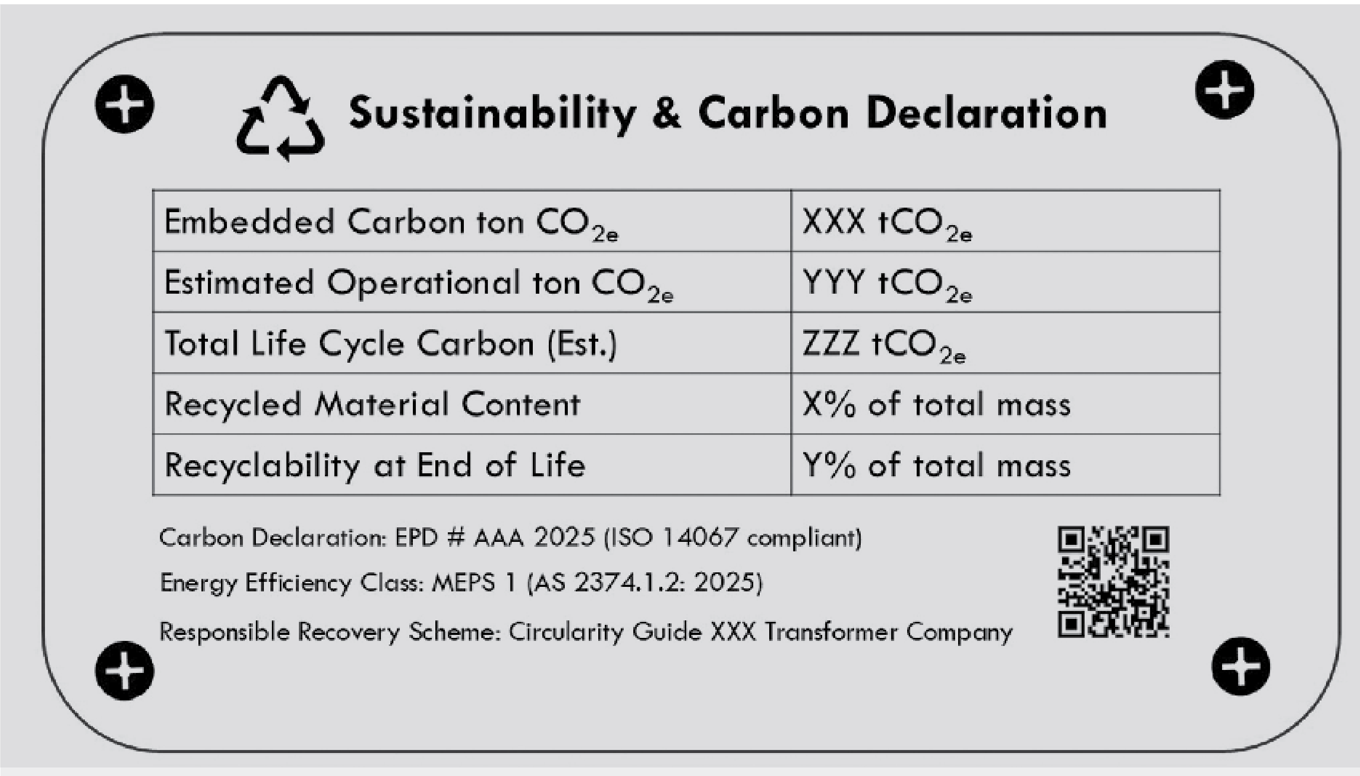

Figure 1. Proposed ECD declaration in transformer nameplate

Just as the evaluation of loss data decades ago transformed procurement economics, carbon data will transform environmental accountability

This connects seamlessly with emerging Environmental, Social & Governance (ESG) reporting tools and utility asset registries.

4.3 Example: Procurement specification language

An example clause for tender documents could read:

"The manufacturer shall declare the transformer's cradle-to-gate embedded carbon footprint in tCO_{2e}, calculated per ISO 14067. The declaration shall appear on the nameplate and in the datasheet. Preference will be given to products with verified Environmental Product Declarations (EPD)."

This mirrors how loss capitalization is already specified, allowing direct integration into scoring matrices [3].

5. Practical considerations

5.1 Data availability

Many manufacturers already track resource use and waste, but not always in carbon terms. Establishing accurate LCAs requires:

- Material bills from Enterprise Resource Planning (ERP) systems,
- Energy consumption per manufacturing process,
- Supplier emission factors,
- Transport distances and modes.

Over time, as supply chains decarbonize, embedded carbon values can be updated and verified annually.

5.2 Confidentiality and benchmarking

Some OEMs may initially resist disclosure, viewing it as proprietary. A pragmatic step could be banded ranges (e.g., "25–30 tCO_{2e}") or certified carbon classes (Bronze, Silver, Gold). This approach allows transparency without exposing sensitive process data.

5.3 Linking with carbon cost

Forward-looking procurement may assign a monetary carbon cost, converting emissions into equivalent dollars. For example, using an internal carbon price of USD 50/tCO_{2e}, a 50 MVA transformer adds a notional $10,000 carbon cost, factored into total lifecycle economics!

Conclusion

The inclusion of embedded carbon on the transformer nameplate is more than a reporting exercise. It is a visible commitment to transparency; an emblem of how the transformer industry can lead in sustainable manufacturing.

Just as the evaluation of loss data decades ago transformed procurement economics, carbon data will transform environmental accountability.

In time, a nameplate that reads both "ONAN 50 MVA, 138/69 kV" and "Embedded Carbon: 190 tCO_{2e}" will be recognized as the hallmark of a net-zero-aligned transformer.

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PEER REVIEWED

Author

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