LCA equations and parameters

Parameters and value:

\( E_{rm} \) — the energy consumption of raw materials;

\( E_w \) — the energy consumption of waste materials in manufacture;

\( E_m \) — the energy consumption in the material phase;

\( m \) — the mass of raw materials;

\( M_{cf} \) — the mass correcting factor to compensate the mass loss in manufacture;

\( H_v \) — the embodied energy constant of virgin raw materials;

\( H_{rc} \) — the embodied energy constant of the recycled part in raw materials;

\( R_c \) — the fraction of the recycled part in raw materials;

\( H_e \) — the energy constant of waste collection;

\( H_{rw} \) — the embodied energy constant of waste materials;

\( N \) — the total number of ingredients in the formulation;

\( Z_i \) — the number of processes for ingredient \( i \);

\( H_R \) — the energy constant of a raw material manufacture process;

\( m_{Ri} \) — the mass of ingredient \( i \);

\( M_{cfRi,j} \) — the mass correction factor of process number \( j \) for ingredient \( i \);

\( Y \) — the total process number of a semi-finished product;

\( p \) — the percentage of the cut-off materials in a process;

\( H_p \) — the energy constant of a semi-finished product manufacture process;

\( Cf_j(m) \) — the mass conversion factor of the process number \( j \) of the semi-finished product;

\( E_{mfr} \) — the manufacture energy of raw materials;

\( E_{mfp} \) — the manufacture energy of the semi-finished product;

\( E_m \) — the energy consumption in manufacture stage;

\( E_t \) — the energy consumption in transport stage;

\( n \) — the number of transports;

\( H_{tj} \) — the energy constant of transport number \( j \);

\( D_j \) — the distance of transport number \( j \);

\( E_d \) — the energy consumption in use stage;

\( H_u \) — the energy constant of use depending on the vehicles it is applied;

\( C_e \) — the energy equivalence for electric transporting tools depending on countries;

\( DL \) — the lifelong working days of the product;

\( D_{day} \) — the average moving distance per day of the transporting tool in life cycle;

\( E_d \) — the energy consumption of disposal;

\( EO\)L — the way of end-of-life;

\( E \) — the total energy consumption in lifecycle;

\( CF \) — the total CO\(_2\) footprint in lifecycle;

\( \alpha \) — the conversion factor between energy and CO\(_2\);

\( CF_m, CF_{mf}, CF_{mfr}, CF_u \) and \( CF_d \) are corresponding parameter of CO\(_2\) footprint in the material, manufacture, transport, use and disposal phase, respectively. The detail parameters labeled ‘CF’ for CO\(_2\) footprint has the same meaning as labeled with ‘E’ for energy consumption. For example, \( H_v \) means the energy constant of virgin raw materials, while \( CF_v \) represents the CO\(_2\) constant of virgin raw materials.
Table 1: Key parameter values for LCA calculation.

| Energy | parameters | $H_r$ (MJ/kg) | $H_{ri}$ (MJ/kg) | $H_{c2}$ (MJ/kg) | $H_c$ (MJ/kg) | $H_{ci}$ (MJ/kg) | $H_d$ (MJ/kg) | $H_u$ (MJ/kg) |
|--------|------------|---------------|------------------|-----------------|---------------|-----------------|---------------|---------------|
| Recycled powder | 0.92 | 0 | 0.3 | 0.2 | 0.92 | 0.35 | 0.82 | 1.7 |
| Phenolic resin | 92.6 | 0 | 0.3 | 0.2 | 92.5 | 0.35 | 0.82 | 1.7 |

formula materials | Not listed

| CO₂ | parameters | $CF_r$ (g/kg) | $CF_{ri}$ (g/kg) | $CF_{c2}$ (g/kg) | $CF_c$ (g/kg) | $CF_{ci}$ (g/kg) | $CF_d$ (g/kg) | $CF_u$ (g/kg) |
|-----|------------|---------------|------------------|-----------------|---------------|-----------------|---------------|---------------|
| Recycled powder | 81 | 0 | 23 | 14 | 81 | 25 | 59 | 72 |
| Phenolic resin | 4310 | 0 | 23 | 14 | 4210 | 25 | 59 | 72 |

formula materials | Not listed

| Common | parameters | $R_c$ | $m_f$ (g) | $p_f$ | $D_1$ (km) | $D_2$ (km) | $C_e$ | $\alpha$ | $DL$ | $D_{day}$ (km) | $EOL$ |
|--------|------------|-------|-----------|-------|------------|------------|-------|--------|------|--------------|-------|
| Recycled powder | 0 | 145.5 | 5% | 0 | 500 | 50 | 1 | 0.07 | 3000 | 15 | landfill |
| Phenolic resin | 0 | 12.7 | 5% | 0 | 500 | 50 | 1 | 0.07 | 3000 | 15 | landfill |

formula materials | Not listed

Equations:

$$E_{rm} = m \cdot M_{cf} \cdot (H_r \cdot (1 - R_c) + H_{rc} \cdot R_c) \quad (1)$$

$$E_w = m \cdot (M_{cf} - 1) \cdot (H_c + H_{rw}) \quad (2)$$

$$E_m = E_{rm} + E_w \quad (3)$$

$$E_{mf} = \sum_{i=1}^{N} \sum_{j=1}^{Z} H_{Ri,j} \cdot m_{Ri} \cdot M_{cfRi,j} \quad (4)$$

$$M_{cfRi,j} = \prod_{k=1}^{Z_{ij}} \frac{1}{1 - p_k} \quad (5)$$

$$E_{mf} = \sum_{j=1}^{N} H_{Pj} \cdot C_f_j(m) \cdot \prod_{r=1}^{Y_{j-1}} 1 \quad (6)$$

$$E_m = E_{mf} + E_{mf} \quad (7)$$

$$E_t = \sum_{j=1}^{N} H_{tj} \cdot m \cdot D_j \quad (8)$$

$$E_u = H_u \cdot m \cdot C_e \cdot DL \cdot D_{day} \quad (9)$$

$$E_d = H_d \cdot m \quad (10)$$

$$E = E_m + E_{mf} + E_t + E_u + E_d \quad (11)$$

$$C_{Fm} = m \cdot M_{cf} \cdot (C_{Fr} \cdot (1 - R_c) + C_{Fc} \cdot R_c) + m \cdot (M_{cf} - 1) \cdot (C_{Fr} + C_{Fw}) \quad (12)$$

$$C_{Fmf} = \sum_{i=1}^{N} \sum_{j=1}^{Z} C_{FRI,j} \cdot m_{Ri} \cdot \prod_{k=1}^{Z_{ij}} \frac{1}{1 - p_k} + \sum_{j=1}^{N} H_{Pj} \cdot C_f_j(m) \cdot \prod_{r=1}^{Y_{j-1}} 1 \quad (13)$$

$$C_{Ft} = \sum_{j=1}^{N} C_{Ftj} \cdot m \cdot D_j \quad (14)$$

$$C_{Fu} = C_{Fu} \cdot m \cdot C_e \cdot DL \cdot D_{day} \quad (15)$$

$$C_{Fd} = \alpha \cdot E_d \quad (16)$$

$$C_{F} = C_{Fm} + C_{Fmf} + C_{Ft} + C_{Fu} + C_{Fd} \quad (17)$$

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