Application of a costing model consistent with LCA to the production of pasta in a small-sized firm

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Background and motivation:

• Relevance of costing models in sustainability analysis;
  • Strong complementary relationship between environmental awareness and operational effectiveness is likely to exist (Newman and Hannah, 1996).

• Applications to food products (nondurable goods) show peculiar implementation and methodological problems:
  • Few applications of LCC to food products and, more generally, to nondurable products;
  • Mostly, investments in some new food production plant;
  • System boundaries and linkages with the life cycle inventory of the food product unclear/inconsistent;
  • Major need to explore the implications of “consistency” of costing with LCA from a computational perspective.
Objective and scope:

• To show, by means of an illustrative case study how to:
  • Model in details the food operations chain actually controlled by one relevant actor (the producer of fresh pasta), by using IOA principles;
  • Perform practical non-deterministic analysis;
  • Integrate the results obtained within an LCI dataset

• Application context: to support
  • The integrated control and management of physical flows and costs within a multiproduct, multistage production system that
    • Already exists and operate,
    • Produces non-durable products (e.g. food products);
  • The supply of site-specific information for a LCI.
Which perspective is the relevant one?
  + producer, user, supply chain, society, market, or the whole physical life-cycle

Which economic measure to include: costs or cash flows?

Which environmental costs?
  + External; internal material flow-related

Which approaches should be adopted to include economic aspects?
  + Toolbox (combination); extension (integration); hybrid models

Which focus?
  + Data gathering; computational mechanisms

Type of data
  + Site dependent; site specific; Inclusion of time (dynamics)
Production of fresh pasta: process network
### Processes (material flows not balanced - ref.: one process run)

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dough type 1</strong></td>
<td>kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Dough type 2</strong></td>
<td>kg</td>
<td></td>
<td></td>
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<tr>
<td><strong>Mix flour type 1</strong></td>
<td>kg</td>
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<tr>
<td><strong>Mix flour type 2</strong></td>
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<tr>
<td><strong>Mix flour type 3</strong></td>
<td>kg</td>
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<tr>
<td><strong>Flour type 1</strong></td>
<td>kg</td>
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<tr>
<td><strong>Flour type 2</strong></td>
<td>kg</td>
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<tr>
<td><strong>Flour type 3</strong></td>
<td>kg</td>
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<tr>
<td><strong>Flour type 4</strong></td>
<td>kg</td>
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<tr>
<td><strong>Flour type 5</strong></td>
<td>kg</td>
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<tr>
<td><strong>Carton box</strong></td>
<td>kg</td>
<td></td>
<td></td>
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<tr>
<td><strong>Sesame type 1</strong></td>
<td>kg</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td><strong>Sesame type 2</strong></td>
<td>kg</td>
<td></td>
<td></td>
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<tr>
<td><strong>Water (kg)</strong></td>
<td>L</td>
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<tr>
<td><strong>Electric power</strong></td>
<td>kWh</td>
<td></td>
<td></td>
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<tr>
<td><strong>Carbon dioxide</strong></td>
<td>kg</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td><strong>Fixed cost overheads</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Electric energy (kWh)</strong></td>
<td>250kWh</td>
<td>F</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Natural Gas</strong></td>
<td>M3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Water (incl. feed)</strong></td>
<td>m3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Labour (incl. wages)</strong></td>
<td>min</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fixed emissions CO2</strong></td>
<td>kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
1 Set and exogenous production plan

Production Program (1 shift)

<table>
<thead>
<tr>
<th>Product Type</th>
<th>Unit</th>
<th>Final Deliveries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dough type 1</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Dough type 2</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Formed pasta type 1</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Formed pasta type 2</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Formed pasta type 3</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Pasteurized pasta type 1</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Pasteurized pasta type 2</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Pasteurized pasta type 3</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Pre-dried pasta type 1</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Pre-dried pasta type 2</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Pre-dried pasta type 3</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Coated pasta type 1</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Coated pasta type 2</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Coated pasta type 3</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Packaging pasta type 1</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Packaging pasta type 2</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Packaging pasta type 3</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Overheated steam</td>
<td>kg</td>
<td></td>
</tr>
</tbody>
</table>

(vector of final deliveries)

2 Determine the activity levels of processes

\[ Z_{i,j} \cdot s_j = y_j \rightarrow s_j = Z_{i,j}^{-1} \cdot y_j \]

3 Obtain a balance of material flows

\[
\tilde{B}_{*,j} = \left[ -\frac{M_{*,j}}{N_{i,j}} \right] \cdot \tilde{s}_j \quad \tilde{Z}_{i,j} = Z_{i,j} \cdot \tilde{s}_j
\]

4 Calculate the direct costs of each process

\[
\omega = \begin{bmatrix} p_M^T & p_F^T & \tilde{B}_{*,j} \\ F & R_{*,j} \end{bmatrix}
\]

5 Calculate the unit cost of each intermediate and final product

\[
p = \omega \cdot \tilde{Z}^{-1}
\]
6 Associate uncertainty to the parameters and run Monte Carlo Simulation
Turning the costing model (multi-product) into LCA:

- Re-define the vector of final deliveries $y_{LCA \_process}$ such as:
  - It shows just one positive entry (the amount of output of one chosen product type)

- Solve: $\tilde{Z}_{1,1} \cdot s_{LCA \_process} = y_{LCA \_process}$

- Obtain the unit process for use in LCA as a column vector:
  $$\begin{bmatrix}
  \tilde{Z}_* \\
  \tilde{B}_* \\
  F \\
  R_* \\
  \end{bmatrix} \cdot s_{LCA \_process} = \begin{bmatrix} a \\ b \end{bmatrix}$$

- Link properly the new unit process within a process network database to form a LCI

- Run LCA
Example of contribution analysis (Ref: 1kg of fresh pasta “type 2”) by using CMLCA 5.1 and Ecoinvent Database

Example of combination of cost and environmental coordinates (Ref: 1kg of fresh pasta “type 2”)
Additional steps: process inefficiencies (scraps/by-products) and allocation

Entries of $C(2)$ multiplied by $\lambda=0.998$ and $(1-\lambda)$ respectively
Calculate the recycling percentages (for \( n_I \) production processes and \( k \) waste types)

\[
\forall k, (\rho_I)_k = \sum_{j=1}^{n_I} (N_{I,I})_{k,j} \times (s_I)_j
\]

\[
\forall k, (\eta_I)_k = \sum_{j=1}^{n_I} (\overline{N}_{I,I})_{k,j} \times (s_I)_j
\]

\[
r_k = \frac{(\eta_I)_k}{(\rho_I)_k}
\]

\[
r_I = [r_i \ldots r_k \ldots]^T
\]

Turn the different types of wastes/by-products into the demand of treatment processes

\[
Q = [q_{ik}]
\]

where \( 0 \leq q_{ik} \leq 1 \)

\[
\tilde{Z}_{II,I} = [-Q \cdot (I - \hat{r}_I)] \cdot (\overline{N}_{I,I} \cdot \hat{s}_I)
\]

in this case study: waste collection only and no recycling of waste types generated by the treatment processes (simplest case)

Calculate the scaling factors again, taking into account the treatment processes

\[
s_{II} = X^{-1} \cdot y_{II}
\]

where

\[
X = \begin{pmatrix}
\tilde{z}_{I,I} & \tilde{z}_{II,I} \\
\tilde{Z}_{II,I} & \tilde{Z}_{III,II}
\end{pmatrix}
\]

\[
\tilde{X} = X \cdot \tilde{s}_{II}
\]

and

\[
\tilde{B} = (\tilde{b}_{.,I} \mid \tilde{b}_{.,II} ) \cdot \tilde{s}_{II}
\]
Calculate the direct process costs and the unit costs again

\[ \omega = \begin{bmatrix} p^T_M & p^T_F \end{bmatrix} \begin{bmatrix} \tilde{B} \\ F \end{bmatrix} \quad \text{and} \quad p = \omega \cdot \tilde{X}^{-1} \]

The cost of producing and disposing of waste (non value-added activity) is now explicit

<table>
<thead>
<tr>
<th>Costs (with allocation)</th>
<th>unit</th>
<th>C(2)</th>
<th>C(SCRAP)</th>
<th>E(2)</th>
<th>E(SCRAP)</th>
<th>F(2)</th>
<th>F(SCRAP)</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct process costs (€)</td>
<td>kg</td>
<td>3.058</td>
<td>0.002</td>
<td>3.027</td>
<td>0.003</td>
<td>21.94</td>
<td>0.45706</td>
<td>10.48</td>
</tr>
<tr>
<td>Unit cost of formed pasta type 2</td>
<td>€/kg</td>
<td>0.35</td>
<td>0.75</td>
<td>0.39</td>
<td>0.795</td>
<td>0.50</td>
<td>0.912056</td>
<td>0.4</td>
</tr>
</tbody>
</table>
Concluding remarks

- Advantages of matrix-based costing:
  + Unlike “traditional LCC” it applies to
    - Non durable good such as food products, not only durable goods;
    - Existing processes, not only to prospective investments.
  + Supports actual managerial decision making processes within the firm;

- Consistency with LCA and integration: a matter of computational structure
  + Theoretically, whatever complex multi-stage multi-product system can be analyzed in sufficient details by Input-Output accounting, and then turned into a black-box unit process for use within LCI;
  + In practice, carefully consider the extent to which it is possible or useful to gain insight into the cost structure of one or more supply chain actors;

- Profitability within the Agri-food supply chain needs careful assessment