Report: LCA of enzyme production and calculation of Key Performance Indicators for Metgen

Gaia Consulting Oy 18.11.2016
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Cradle to Gate LCA of enzyme production

1. Introduction

- This report is part of the project “LCA of enzyme production and calculation of Key Performance Indicators for Metgen” and contains the result for project phase 1: “cradle to gate LCA of Metgen’s enzyme production”.
- Cradle to gate LCA was carried out for Metgen’s OXR enzyme product based on ISO-14040 and 14044.
- Detailed methodology, scope of the analysis and results are presented in this report for:
  - global warming
  - acidification
  - eutrophication
  - photochemical ozone formation.

- The report shall be provided based on the facts and instructions in the specific assignment considering the circumstances at the time of the assignment in accordance with the respective scope of work. We assume that all the information provided to us is accurate and complete and that you have verified the correctness of the disclosed information.
- We assume no responsibility and make no representations with respect to the accuracy or completeness of the information in this report unless otherwise stated. The report should not be regarded, or be relied upon, as a recommendation in decision making concerning any matter referred to in it.
- It should be understood that we do not assert that we have identified all matters included in these documents that may be relevant if these documents are included as disclosures against the warranties of the future agreements. Our review of the documents has only been what we consider appropriate in the context of the scope of our work as set out in our offer.
- Further, we accept no responsibility to update the report in light of subsequent events (after the date of this report).
Cradle to Gate LCA of enzyme production

2. Methodology

- Data:
  - Calculations are based on the process information delivered by Metgen Oy, including
    - Process description
    - Amount of raw materials and production volumes
    - Electricity, steam and water consumption
    - Amount of air emissions and generated effluent

- Calculations:
  - SimaPro LCA software was used for calculations (SimaPro Analyst ver. 8.2.0)
  - For secondary data, mainly Ecoinvent 3.2 data library was utilized.
  - Mass based cut-off criteria of 1.9% was used for an item (resulting overall contribution of 4.1%)
  - Following environmental impact categories were assessed according CML IA* – methodology:
    - Global warming (kg CO2-eq.)
    - Acidification (g SO2-eq.)
    - Eutrophication (g PO4-eq.)
    - Photochemical ozone formation (C2H4-eq.)
  - Significance of various inputs were screened based on varying levels of emissions factors (environmental impacts caused by each materials or process)
  - According to sensitivity results, the issues that cause the biggest environmental impacts were identified and more information were gathered to improve the results.

*methodology developed by the Center of Environmental Science of Leiden Univeristy of The Netherlands.
Cradle to Gate LCA of enzyme production

2. Methodology - Scope of the study: cradle to gate

Upstream processes for raw materials and auxiliary materials (e.g., raw material production for CSA, NaCl, Glucose syrup, etc.)

Production of energy

Production of raw materials, eq. chemicals and auxiliary materials

CORE PROCESS: Enzyme production (from seed preparation to formulation)

Water

Air emissions

1 kg of product at factory gate

Biological waste water treatment

Waste water
Cradle to Gate LCA of enzyme production
2. Methodology - Used assumptions and emissions factors for calculations (1/3)

<table>
<thead>
<tr>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electricity</strong></td>
</tr>
<tr>
<td>Electricity was purchased from Italian energy company Edison Energia Spa. The share of renewable energy is approximately 37%. Emission factor (CO2) and share of electricity sources reported in company’s sustainability report was used for calculation.*</td>
</tr>
<tr>
<td><strong>Steam</strong></td>
</tr>
<tr>
<td>Information received from Metgen was used in calculation. According to the information, all the steam used in production was produced by natural gas. Water consumption and efficiency parameters were derived from Ecoinvent database v.3.2. (Steam, in chemical industry, RER, production, Alloc Rec U)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Emissions from production</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Air emission</strong></td>
</tr>
<tr>
<td>Amount of air emissions (CO2) was received from Metgen Oy.</td>
</tr>
<tr>
<td><strong>Waste water</strong></td>
</tr>
<tr>
<td>Amount of generated waste water was received from Metgen Oy. Process model for waste treatment plant was derived from Ecoinvent database 3.2 (Wastewater from starch production, CH, treatment of, Alloc Rec) and the process was modified according to the information received from production site.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transportation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transportation</strong></td>
</tr>
<tr>
<td>The transportation distances and modes of raw materials were not available. It was assumed that average transportation distance is 600 km according to Eurostat statistics**. It was assumed that all of the transportation is done by trucks. Transportation of the materials below the cut-off criteria was also included in calculation.</td>
</tr>
</tbody>
</table>

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*Edison Energia, Sustainability Report 2015.
**Eurostat: Average distance of which goods are carried (km), 2014. International transportation, Italy.
Cradle to Gate LCA of enzyme production
2. Methodology - Used assumptions and emissions factors for calculations (2/3):

<table>
<thead>
<tr>
<th>Raw materials:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressed air</td>
<td>Amount of used compressed air was received from Metgen. Process</td>
</tr>
<tr>
<td></td>
<td>model for compressed air production was derived from Ecoinvent</td>
</tr>
<tr>
<td></td>
<td>database 3.2 (Compressed air, 600 KPa gauge, RER, compressed</td>
</tr>
<tr>
<td></td>
<td>air production, Alloc Rec U). The model was modified according</td>
</tr>
<tr>
<td></td>
<td>the data received from the production site (electricity</td>
</tr>
<tr>
<td></td>
<td>consumption, pressure and Edison Energia’s electricity mix.).</td>
</tr>
<tr>
<td>Water</td>
<td>According to the received information, the major part of the</td>
</tr>
<tr>
<td></td>
<td>process water is steam condensate. It was assumed in calculation</td>
</tr>
<tr>
<td></td>
<td>that share of freshwater is 10% of required amount. Information</td>
</tr>
<tr>
<td></td>
<td>from Ecoinvent database 3.2 was used for calculation (Tap</td>
</tr>
<tr>
<td></td>
<td>water, Europe without Switzerland, market for, Alloc Rec, U).</td>
</tr>
<tr>
<td>Yeast extract</td>
<td>Ecoinvent 2.2 database was used for calculation (Yeast past,</td>
</tr>
<tr>
<td></td>
<td>from whey, at fermentation, CH, U).</td>
</tr>
<tr>
<td>CSA</td>
<td>Ecoinvent 3.2 database was used for calculation (Chemical,</td>
</tr>
<tr>
<td></td>
<td>organic, (GLO) production, Alloc Rec U).</td>
</tr>
<tr>
<td>NaCl</td>
<td>Ecoinvent 3.2 database was used for calculation (Sodium</td>
</tr>
<tr>
<td></td>
<td>chloride, powder, RER, production, Alloc Rec U).</td>
</tr>
<tr>
<td>Ammonia</td>
<td>Ecoinvent 3.2 database was used for calculation (Ammonia, liquid,</td>
</tr>
<tr>
<td></td>
<td>RER, market for, Alloc Rec U).</td>
</tr>
<tr>
<td>Lactose</td>
<td>Production of whey was used as estimate. Information was</td>
</tr>
<tr>
<td></td>
<td>received from Ecoinvent 3.2 database (Whey, GLO, market for,</td>
</tr>
<tr>
<td></td>
<td>Alloc Rec U).</td>
</tr>
</tbody>
</table>
**Cradle to Gate LCA of enzyme production**

2. **Methodology - Used assumptions and emissions factors for calculations (3/3):**

<table>
<thead>
<tr>
<th>Raw materials:</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Glucose</strong></td>
<td>Average European raw material consumption for starch production* was used as estimate as primary information about the raw materials used for production and environmental data related to enzymatic hydrolysis of starch was not available from the suppliers. However, results are in line with the LCA study conducted by the European starch industry association**.</td>
</tr>
<tr>
<td><strong>Triton X</strong></td>
<td>Ecoinvent database 3.2 was used for calculation (Diethylene glycol, RER, ethylene glycol production, Alloc Rec, U)</td>
</tr>
<tr>
<td><strong>Glycerol</strong></td>
<td>According to supplier’s information glycerol is produced as a by-product from diesel production although primary data on used raw materials was not available. As an assumption, share of different raw materials (reported by GAIN***) used for production of biodiesel was used for modelling of environmental impacts.</td>
</tr>
<tr>
<td><strong>Ammonium sulfate</strong></td>
<td>Ecoinvent 3.2 database was used for calculation (Ammonium sulfate as N, (RER), ammonium sulfate production, Alloc Rec U).</td>
</tr>
<tr>
<td><strong>Sodium formate</strong></td>
<td>Ecoinvent 3.2 database was used for calculation (Sodium formate, GLO, market for, Alloc Rec U).</td>
</tr>
<tr>
<td><strong>Potassium phosphate</strong></td>
<td>Ecoinvent 3.2 database was used for calculation (Chemical inorganic, GLO, production, Alloc Rec U).</td>
</tr>
</tbody>
</table>

*Starch production in Europe (http://www.starch.eu/wp-content/uploads/2012/06/Slide4-1.jpg)

**The European starch industry association, Life cycle assessment study of starch products for the European starch industry association: sector study

***Global Agricultural Information Network, 2014, EU Biofuels Annual
### Cradle to Gate LCA of enzyme production

#### 3. Results: Results of the LCA study

<table>
<thead>
<tr>
<th></th>
<th>Global warming potential (kg CO2-eq.)</th>
<th>Photochemical ozone formation (kg C2H4-eq.)</th>
<th>Acidification (kg SO2-eq.)</th>
<th>Eutrophication (kg PO4--- eq.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity production</td>
<td>2.96E-01</td>
<td>4.10E-05</td>
<td>6.67E-04</td>
<td>7.84E-05</td>
</tr>
<tr>
<td>Steam production</td>
<td>5.72E-01</td>
<td>4.84E-05</td>
<td>6.16E-04</td>
<td>1.19E-04</td>
</tr>
<tr>
<td>Production of compressed air</td>
<td>9.00E-02</td>
<td>1.29E-05</td>
<td>2.05E-04</td>
<td>2.66E-05</td>
</tr>
<tr>
<td>Production of raw materials</td>
<td>8.43E-01</td>
<td>2.44E-04</td>
<td>5.58E-03</td>
<td>4.59E-03</td>
</tr>
<tr>
<td>Emissions from production</td>
<td>2.98E-02</td>
<td>1.73E-06</td>
<td>5.82E-05</td>
<td>7.64E-04</td>
</tr>
<tr>
<td>Transportation</td>
<td>4.05E-02</td>
<td>5.16E-06</td>
<td>1.08E-04</td>
<td>1.92E-05</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1.87E+00</strong></td>
<td><strong>3.53E-04</strong></td>
<td><strong>7.24E-03</strong></td>
<td><strong>5.60E-03</strong></td>
</tr>
</tbody>
</table>
Cradle to Gate LCA of enzyme production

3. Results: Relative contributions of activities for global warming potential and photochemical ozone formation

Global warming potential (kg CO2-eq.)

- Electricity production: 45%
- Steam production: 30%
- Production of compressed air: 16%
- Production of raw materials: 5%
- Emissions from production: 2%
- Transportation: 2%

Photochemical oxidation (kg C2H4-eq.)

- Electricity production: 69%
- Steam production: 14%
- Production of compressed air: 12%
- Production of raw materials: 4%
- Emissions from production: 1%
- Transportation: 0%
Cradle to Gate LCA of enzyme production

3. Results: Relative contributions of activities for acidification and eutrophication

Acidification (kg SO2-eq.)
- Electricity production: 1%
- Steam production: 9%
- Production of compressed air: 9%
- Production of raw materials: 3%
- Emissions from production: 77%
- Transportation: 1%

Europhication (kg PO4-eq.)
- Electricity production: 0%
- Steam production: 1%
- Production of compressed air: 2%
- Production of raw materials: 14%
- Emissions from production: 82%
- Transportation: 1%
Cradle to Gate LCA of enzyme production

3. Results: Relative contributions of raw materials and activities to overall results

<table>
<thead>
<tr>
<th></th>
<th>Global warming potential</th>
<th>Photochemical ozone formation</th>
<th>Acidification</th>
<th>Eutrophication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>15.8 %</td>
<td>11.6 %</td>
<td>9.2 %</td>
<td>1.4 %</td>
</tr>
<tr>
<td>Steam</td>
<td>30.6 %</td>
<td>13.7 %</td>
<td>8.5 %</td>
<td>2.1 %</td>
</tr>
<tr>
<td>Compressed air</td>
<td>4.8 %</td>
<td>3.6 %</td>
<td>2.8 %</td>
<td>0.5 %</td>
</tr>
<tr>
<td>Water</td>
<td>0.0 %</td>
<td>0.0 %</td>
<td>0.0 %</td>
<td>0.0 %</td>
</tr>
<tr>
<td>Yeast extract</td>
<td>1.9 %</td>
<td>1.6 %</td>
<td>2.1 %</td>
<td>0.9 %</td>
</tr>
<tr>
<td>CSA</td>
<td>3.5 %</td>
<td>8.1 %</td>
<td>3.8 %</td>
<td>1.0 %</td>
</tr>
<tr>
<td>NaCl</td>
<td>0.1 %</td>
<td>0.1 %</td>
<td>0.1 %</td>
<td>0.1 %</td>
</tr>
<tr>
<td>Ammonia</td>
<td>1.9 %</td>
<td>3.4 %</td>
<td>3.5 %</td>
<td>0.2 %</td>
</tr>
<tr>
<td>Lactose</td>
<td>0.1 %</td>
<td>0.1 %</td>
<td>0.2 %</td>
<td>0.2 %</td>
</tr>
<tr>
<td>Glucose</td>
<td>9.4 %</td>
<td>5.3 %</td>
<td>15.8 %</td>
<td>21.0 %</td>
</tr>
<tr>
<td>Triton-X</td>
<td>2.9 %</td>
<td>4.2 %</td>
<td>2.5 %</td>
<td>1.0 %</td>
</tr>
<tr>
<td>Glycerol</td>
<td>24.0 %</td>
<td>44.4 %</td>
<td>47.4 %</td>
<td>56.9 %</td>
</tr>
<tr>
<td>Ammonium sulfate</td>
<td>0.2 %</td>
<td>0.1 %</td>
<td>0.1 %</td>
<td>0.0 %</td>
</tr>
<tr>
<td>Sodium formate</td>
<td>0.1 %</td>
<td>0.1 %</td>
<td>0.1 %</td>
<td>0.1 %</td>
</tr>
<tr>
<td>Potassium phosphate</td>
<td>0.9 %</td>
<td>1.5 %</td>
<td>1.5 %</td>
<td>0.5 %</td>
</tr>
<tr>
<td>Air emission from production</td>
<td>1.2 %</td>
<td>0.0 %</td>
<td>0.0 %</td>
<td>0.0 %</td>
</tr>
<tr>
<td>Waste water from production</td>
<td>0.4 %</td>
<td>0.5 %</td>
<td>0.8 %</td>
<td>13.6 %</td>
</tr>
<tr>
<td>Transportation</td>
<td>2.2 %</td>
<td>1.5 %</td>
<td>1.5 %</td>
<td>0.3 %</td>
</tr>
</tbody>
</table>
Cradle to Gate LCA of enzyme production

4. Sensitivity of overall results (GWP expressed as CO2-eq.) to emission factors

Results (baseline)

Results (emission factor +500%)

- Electricity: +182.7%
- Steam: +221.2%
- Air: +214.2%
- Water effluent: +138.2%
- Yeast extract: +195.3%
- CSA: +162.7%
- NaCl: +121.2%
- Glucose: +203.4%
- Ammonia: +172.3%
- (NH4)2SO4: +148.5%
- KH2PO4: +195.3%
- Lactose: +171.2%
- Triton-x: +195.3%
- Na formate: +195.3%
- Glycerol: +195.3%
- Water: +195.3%
- Transportation: +195.3%
Cradle to Gate LCA of enzyme production

4. Sensitivity of overall results (Photochemical ozone formation, kg C2H4-eq.) to emission factors

![Graph showing sensitivity of overall results to emission factors.](image-url)

- Results (baseline)
- Results (emission factor +500%)
Cradle to Gate LCA of enzyme production
4. Sensitivity of overall results (Acidification, kg SO2-eq.) to to emission factors

Results (baseline)
Results (emission factor +500%)
Cradle to Gate LCA of enzyme production

4. Sensitivity of overall results (Eutrophication, kg PO4----eq.) to emission factors
### Cradle to Gate LCA of enzyme production

#### 4. Uncertainty of the results (1/2)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Data quality</th>
<th>Sensitivity</th>
<th>Contribution</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity production</td>
<td>Good</td>
<td>Overall results are highly sensitive to electricity mix used in calculations.</td>
<td>Electricity production contributes mostly to global warming potential (16%). The impacts to other impact categories ranges from small to moderate.</td>
<td>Even though results are highly sensitive for electricity production mix, the uncertainty is quite low as more detailed information related to energy mix used was available.</td>
</tr>
<tr>
<td>Steam production</td>
<td>Fair</td>
<td>Overall results are highly sensitive to amount and origin of steam.</td>
<td>Steam production contributes the most to the global warming potential (31%). The impacts to other impact categories are from small to moderate.</td>
<td>Some uncertainties are related to the amount of steam consumed, but more detailed information was available from steam production, which decrease the uncertainties.</td>
</tr>
<tr>
<td>Production of compressed air</td>
<td>Good</td>
<td>Overall results are highly sensitive to amount and origin of the electricity used for production of compressed air.</td>
<td>Production of compressed air have small impact (less than 5 %) to results in every impact category.</td>
<td>Uncertainty can be considered to be relatively low as the main part of the impacts are caused by electricity consumption and more detailed information related to energy mix was available.</td>
</tr>
<tr>
<td>Emissions from production</td>
<td>Fair</td>
<td>Overall results are not sensitive to air emission from production. Small sensitivities are related to impacts from effluent treatment regarding eutrophication</td>
<td>Emissions from the production has small impact on the overall results. Only generated waste water have some impact on the eutrophication potential.</td>
<td>Some uncertainty are related to waste water treatment, but the impacts and sensitivity to overall results are small.</td>
</tr>
</tbody>
</table>
### Cradle to Gate LCA of enzyme production

#### 4. Uncertainty of the results (2/2)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Data quality</th>
<th>Sensitivity</th>
<th>Contribution</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission from raw materials production</td>
<td>From moderate to good</td>
<td>Results are highly sensitive for production of glucose and glycerol. Overall results have very small or negligible sensitivity to production of other raw materials.</td>
<td>The production of glycerol have a great impact on photochemical oxidation, acidification and eutrophication. Also glucose have some impact on the results. Production of other raw materials have negligible or small impact on overall results.</td>
<td>Some uncertainties are related to environmental impact caused by production of glycerol and glucose. The best available estimates and raw material mixes were used for calculation. For other raw materials, uncertainty varies from poor to good, but as their sensitivity or impact are negligible or small, these uncertainties have very small impacts on overall results.</td>
</tr>
<tr>
<td>Transportation</td>
<td>Moderate</td>
<td>Overall results are not sensitive for transportation activities.</td>
<td>Environmental impacts from transportation activities have small influence on the overall results.</td>
<td>High uncertainties are related to environmental impacts, but their share and sensitivity to results are small.</td>
</tr>
</tbody>
</table>
LCA studies on enzyme production: A review on selected results
LCA studies on enzyme production: A review on selected results

Introduction

- The present LCA study assessed production of OXR enzyme product of Metgen (1).
- LCA studies on enzyme production have been carried out and published earlier e.g. by Novozymes (2).
- The present LCA study and the aforementioned Novozymes LCA study are separate studies which have been carried out with individual LCA system scopes and assumptions described in study reports. Due to this, the studies differ from each other e.g. by the time when they have been conducted, used data sources, methods and therefore the results are not directly comparable.
- However, the results of the Novozymes LCA study and the present LCA study are summarized here to give an overview about the existing information on environmental impacts caused by industrial production of different types of enzymes based on these two studies.
- It is important to bear in mind that specific processing conditions in enzyme production affect the environmental impacts of enzyme products (global warming, acidification, eutrophication, photochemical ozone formation)

LCA studies on enzyme production: A review on selected results

Summary of selected results (global warming, acidification, eutrophication, photochemical ozone formation)

Enzyme products by Novozymes (1)

- **Enzyme A**
  - Bacterial alpha amylase

- **Enzyme B**
  - Gungal gluco amylase

- **Enzyme C**
  - Fungal phytase

- **Enzyme D**
  - Bacterial protease

- **Enzyme E**
  - Bacterial amylase

Enzyme product by Metgen (2)

- **OXR**

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Project phase 2 and 3: Key Performance Indicators
**Key Performance Indicators**

**Introduction**

- This report is part of the project “LCA of enzyme production and calculation of Key Performance Indicators for Metgen” and contains the result for project phases 2 and 3:
  - Key performance indicators for TMP production
  - Key performance indicators for tissue production
  - Key performance indicators for fluted paper production
- Key performance indicators were specified based on Metgen’s needs
- Analysis and calculation of key performance indicators was carried out using mill trial data received from Metgen and available public data sources.

- The report shall be provided based on the facts and instructions in the specific assignment considering the circumstances at the time of the assignment in accordance with the respective scope of work. We assume that all the information provided to us is accurate and complete and that you have verified the correctness of the disclosed information.
- We assume no responsibility and make no representations with respect to the accuracy or completeness of the information in this report unless otherwise stated. The report should not be regarded, or be relied upon, as a recommendation in decision making concerning any matter referred to in it.
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**Key Performance Indicators**

**TMP Production: Energy intensity of primary refining**

- Energy intensity of primary refining in TMP production was benchmarked between conventional and enzyme enhanced thermomechanical pulping of softwood in a paper mill producing mechanical paper grades.
- Energy intensity of TMP primary refining is shown as specific use of electricity (kWh/t) when refining to a constant target freeness (CSF) in a mill trial.
- Additional energy intensity benefits could be achieved via savings in steam consumption.
- Relevant pulp and paper quality parameters were analyzed and paper machine runnability monitored throughout the trial to identify any potential co-benefits and trade-offs.

**KEY IMPACTS AND BENEFITS:**

- **Energy intensity of TMP primary refining reduced 12.5%**. Additional energy savings can be achieved in secondary refining.
- For example for a mill with yearly production of 300 000 t, this means annual electricity savings of approx. 45 GWh.
- Favourable fiber properties: equal fibre length, increased fibrillation, drastically reduced shives content (-50 %).
- Co-benefits in reduced energy costs and GHG emissions together with increased strength, which enables savings in use of chemical pulp.
- Trade-off in minor reduction of bulk (1-2%).

![Comparison of Conventional and Enzyme Enhanced Primary Refining](image)
**Key Performance Indicators**

**TMP Production: CO2 emission intensity of primary refining**

- Carbon dioxide emission intensity of TMP production was assessed based on electricity use in TMP primary refining to a constant freeness level.
- Emission calculation was based on average European electricity grid emission factor*.
- Benchmarking was carried out between conventional and enzyme enhanced thermochemical pulping of softwood in a paper mill producing mechanical paper grades based on results of a mill trial.

**KEY IMPACTS AND BENEFITS:**

- Carbon dioxide emissions from electricity production decreased 84 kg / ton refined pulp.
- For example for a mill with yearly production of 300,000 tons, this means annual CO2 emissions reduction of 25,000 t.
- The amount of saved CO2 emissions equals to emissions released from yearly heating of over 4000 town houses**.

<table>
<thead>
<tr>
<th>Conventional primary refining (kg CO2 / t)</th>
<th>Enzyme enhanced primary refining (kg CO2 / t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>670</td>
<td>586</td>
</tr>
</tbody>
</table>

*Average European electricity mix is used for calculation, information for emissions factor of electricity is derived from European Environment Agency.
** If electricity is used for heating, approximate house size of 120 m2 used.
Key Performance Indicators
Tissue production: Production efficiency

- Production efficiency in tissue production was benchmarked between conventional and enzyme enhanced tissue production
- Enzyme treatment was used prior to refining, when refining to a constant tensile strength target
- 100 % of household waste based DIP was used as raw material
- Production efficiency is shown as the daily production volume increase based on mill trial results
- Relevant operational and quality parameters were analyzed and monitored to identify any co-benefits as well as trade offs.

IMPACTS AND BENEFITS:
- Production efficiency increase of 8 % due to increase in speed of the paper machine and decreased break time without increase in drying temperatures
- For example for a mill with yearly production of 60 000 tons, this means annual production increase of 5 000 tons
- Co-benefits in lower specific energy consumption of refining (-35-60 %) and improved stretch, leading to reduced maintenance need for the creping blade.
- For example, for a mill with yearly production of 60 000 tons, this means annual electricity savings of 1350 MWh
Key Performance Indicators
Fluted paper production: Production efficiency

- Production efficiency in fluted paper production was benchmarked between conventional and enzyme enhanced fluted paper production
- Production efficiency is shown as the daily production volume increase based on mill trial results
- Relevant operational and quality parameters were analyzed and monitored to identify any co-benefits as well as trade offs.

**IMPACTS AND BENEFITS:**
- In enzyme enhanced production efficiency increased 2% due to reduced amount of web breaks without compromising key quality parameters (CMT, CCT, SCT). In addition, due to decreased COD levels production volume can be further increased as waste water treatment capacity typically is bottleneck in fluted paper production.
- For example for a mill with yearly production of 300 000 tons, this means annual production increase of at least 5 400 tons.
- Co-benefit in specific energy consumption reduction (10-12 kWh/t).

### 850
Conventional fluted paper production (t/d)

### 865
Enzyme enhanced fluted paper production (t/d)
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