LCA applied to palm oil

Malaysian Palm oil

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Programme

- **Goal and scope**
  - System boundaries
  - Life cycle inventory: critical emissions
  - LCA-results: palm oil and improvement options
Vegetable oils: production volume

- Most important oils: Palm, soybean (constrained), rapeseed
- High growth rate (Biodiesel and increasing food intake)
- Significant land use impacts in SE-Asia and S-America

Based on FAOSTAT
Goal and scope

- **Purpose:**
  - Environmental assessment of Malaysian palm oil and palm oil at United Plantations Berhad
  - Identification and assessment of improvement options
    - Capturing and utilisation of methane from oil mill effluent
    - Utilisation of biomass (EFB) for electricity generation
    - Mineral soils versus peat soils
  - Functional unit
    - 1 tonne of refined palm oil for food purposes at refinery gate

Refined oil; neutralised, bleached and deodorised oil; NBD oil
Goal and scope

- Modelling: consequential
  - Actual affected/marginal suppliers included
  - Allocation is avoided by system expansion
- Data: good data availability
  - **Plantation:** Fertiliser, pesticides, fuels, yield profiles, capital goods (United Plantations Berhad)
  - **Oil mill & refinery:** Energy balance, stack emissions, methane measurements, capital goods (United Plantations Berhad)
  - **Emissions:** Parameterised model based on nutrient balances, emission factors: mainly IPCC methodology reports
- LCI A-method
  - Stepwise v1.1 (www.lca-net.com)
  - [www.plan.aau.dk/~jannick/research](http://www.plan.aau.dk/~jannick/research)
Palm oil production
Oil palm plantation

Schmidt (2008), Life cycle assessment of palm oil at United Plantations Berhad. United Plantations Berhad
Palm oil mill

Schmidt (2008), Life cycle assessment of palm oil at United Plantations Berhad. United Plantations Berhad
## Product system and material flows

### Palm oil (PO), Malaysia

- **Oil palm plantation**: 4.651 t FFB
  - **Palm oil mill**: 0.929 t CPO, 0.247 t kernels
    - **Palm kernel oil mill**: 0.111 t crude PKO, 35.5 kg ffa
      - **Refinery**: 0.893 t NBD PO, 4.2 kg ffa
        - **Refinery**: 0.107 t NBD PKO
          - **1.000 t NBD PO+PKO**: 39.7 kg fodder fat, 0.129 t PKC
            - 0 kg protein, 92 SFU energy
            - 19.2 kg protein, 102 SFU energy

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Schmidt (2008), Life cycle assessment of palm oil at United Plantations Berhad. United Plantations Berhad
Programme

• Goal and scope
• System boundaries
  • Life cycle inventory: critical emissions
  • LCA-results: palm oil and improvement options
System delimitation: land use

- Agr. Stage: Land use change – how?

1 ha rapeseed in DK
\[ \div 1 \text{ ha barley in DK} + 1.8 \text{ ha barley in Canada} \]

\[ 5230 \text{ kg barley} \]
System delimitation: land use

Schmidt (2008), System delimitation in agricultural consequential LCA. IntJLCA
System delimitation: co-products

- Oil mill stage: Handling of co-products

- Palm oil
  - Fodder: PKC
  - Fodder energy
  - Fodder protein
  - Displaces Barley
  - Displaces Soybean meal

© United Plantations Berhad
System delimitation: co-products

**Marginal fodder energy:**
Barley from Canada

**Marginal fodder protein:**
Soybean meal from Brazil

**Marginal vegetable oil:**
Palm oil from Malaysia/Indonesia

**Marginal land:**
MY: Grassland/forest
CAN: Grassland
Brazil: Savannah/forest
System delimitation: co-products, solving the loop

<table>
<thead>
<tr>
<th>Product component</th>
<th>Vegetable oil, per kg oil</th>
<th>Soybean meal, per kg meal</th>
<th>Palm kernel cake, per kg meal</th>
<th>Barley, per kg barley</th>
<th>Fodder fat, per kg fodder fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>1 kg oil</td>
<td>0 kg meal</td>
<td>0 kg oil</td>
<td>0 kg meal</td>
<td>0 kg meal</td>
</tr>
<tr>
<td>Protein</td>
<td>0 g protein</td>
<td>436 g protein</td>
<td>149 g protein</td>
<td>91.8 g protein</td>
<td>0 g protein</td>
</tr>
<tr>
<td>Fodder energy</td>
<td>0 SFU</td>
<td>1.20 SFU</td>
<td>0.791 SFU</td>
<td>0.952 SFU</td>
<td>2.31 SFU</td>
</tr>
</tbody>
</table>

Schmidt (2010), Comparative life cycle assessment of rapeseed oil and palm oil. IntJLCA
System delimitation: co-products, solving the loop

1 t palm oil

\[
\begin{align*}
1000 \text{ kg oil/t PO} & \quad + \quad 249 \text{ kg oil/t SM} & \quad + \quad 0 \text{ kg oil/t BL} & = & \quad 1000 \text{ kg oil/t PO} \\
18.5 \text{ kg prot./t PO} & \quad + \quad 436 \text{ kg prot./t SM} & \quad + \quad 91.8 \text{ kg prot./t BL} & = & \quad 0 \text{ kg prot./t PO} \\
98.0 \text{ SFU/t PO} & \quad + \quad 1200 \text{ SFU/t SM} & \quad + \quad 952 \text{ SFU/t BL} & = & \quad 0 \text{ SFU/t PO}
\end{align*}
\]
Programme

• Goal and scope
• System boundaries

• Life cycle inventory: critical emissions
• LCA-results: palm oil and improvement options
Emissions inventory: agricultural stage

- N-balance: N\textsubscript{2}O, NH\textsubscript{3}, N\textsubscript{2}, NO, NO\textsubscript{3}\textsuperscript{-}
- P-balance: PO\textsubscript{4}
- CO\textsubscript{2} from peat

Schmidt (2008), Life cycle assessment of palm oil at United Plantations Berhad. United Plantations Berhad
Dynamic balance throughout the oil palm life cycle

Net inputs:
1) Net input
2) Release from decomposition of biomass
3) Uptake: Changes in stored nutrients (excluding harvested FFB)

Accessible nutrients for uptake and losses

Net outputs:
4) Harvested FFB
5) Surplus

- $\text{N}_2\text{O}-\text{N}$ (IPCC 2000)
- $\text{NH}_3\text{-N}$ (DK model)
- $\text{NO}-\text{N}$ (FAO and IFA)
- $\text{N}_2\text{-N}$ (DK model)
- $\text{NO}_3^- -\text{N}$ (the rest)

Schmidt (2008), Life cycle assessment of palm oil at United Plantations Berhad. United Plantations Berhad
Dynamic balance throughout the oil palm life cycle

Release (t/ha y)

Standing biomass: 4.31 t/ha y

Release from decomposition of felled palms, t/ha y

Old standing biomass: 47.45 t/ha y

Standing biomass of:
- trunk
- fronds
- male flowers

Uptake: biomass in standing stock (not harvested), t/ha y

Release minus uptake, t/ha y

Release (t/ha y)

Sum

Release from decomposition of pruned fronds, t/ha y

Uptake: biomass in fronds to be pruned, t/ha y

Release minus uptake, t/ha y

Release (t/ha y)

Pruned fronds: 10.7 t/ha y

Fronds: 10.7 t/ha y

Sum

Emission as kg emission/ha

<table>
<thead>
<tr>
<th>Mineral soils</th>
<th>Peat soils</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia to air (kg NH₃/ha)</td>
<td>13.8</td>
</tr>
<tr>
<td>N₂O to air (kg N₂O/ha)</td>
<td>11.2</td>
</tr>
<tr>
<td>NO to air (kg NO/ha)</td>
<td>2.71</td>
</tr>
<tr>
<td>Nitrate to water (kg NO₃/ha)</td>
<td>418</td>
</tr>
</tbody>
</table>

Schmidt (2008), Life cycle assessment of palm oil at United Plantations Berhad. United Plantations Berhad
CO₂ from cultivation of peat

- IPCC (2003)
  - 5.0 t CO₂/ha yr (3.0-14.0): drained managed tropical forests
  - 73 t CO₂/ha yr (7.3-139): cropland
- Henson (2004)
  - 27.5 t CO₂/ha yr: oil palm
- Reijnders and Huijbregts (2006)
  - 37-55 t CO₂/ha yr: oil palm
- Hooijer et al. (2006)
  - 54-90 t CO₂/ha yr: oil palm, level depends on drainage depth

\[
\text{CO}_2 \text{ emission from peat (t CO}_2/\text{ha y}) = 27.5 - 0.37 \times (75 - \text{DD})
\]

DD is the drainage depth measured in centimetres (cm).
Emissions inventory: palm oil mill stage

CH₄

Particles
Methane from palm oil mill effluent

Schmidt (2008), Life cycle assessment of palm oil at United Plantations Berhad. United Plantations Berhad

<table>
<thead>
<tr>
<th>Method</th>
<th>Conventional system (no EFB press, no decanter)</th>
<th>United Plantations palm oil mill (with EFB press and decanter)</th>
<th>United Plantaion mill (biogas plant)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Emission to air</td>
<td>Emission to air</td>
<td>Captured in digester</td>
</tr>
<tr>
<td>IPCC-method: Figures taken from Figure 5.16 and Figure 5.17</td>
<td>8.7 kg CH$_4$/t FFB</td>
<td>11.4 kg CH$_4$/t FFB</td>
<td>9.95 kg CH$_4$/t FFB</td>
</tr>
<tr>
<td>Yacob et al. (2006): 13.1 kg CH$_4$/t POME. This is combined with figures in Figure 5.16</td>
<td>9.2 kg CH$_4$/t FFB</td>
<td>10.3 kg CH$_4$/t FFB</td>
<td>-</td>
</tr>
<tr>
<td>Measurements in Jendarata biogas plant: 24.8 Nm$^3$ biogas/t FFB. This is combined with CH$_4$ content in biogas at 62.5% and density of methane at 0.713 kg/Nm$^3$</td>
<td>-</td>
<td>-</td>
<td>11.0 kg CH$_4$/t FFB</td>
</tr>
<tr>
<td>Deviation</td>
<td>8%</td>
<td>-10%</td>
<td>11%</td>
</tr>
<tr>
<td>Applied figures</td>
<td>8.7 kg CH$_4$/t FFB</td>
<td>11.4 kg CH$_4$/t FFB</td>
<td>11.0 kg CH$_4$/t FFB</td>
</tr>
</tbody>
</table>
# Stack emissions from palm oil mills

<table>
<thead>
<tr>
<th>Stack emission monitoring reports</th>
<th>NO$_2$ (g/kg dry fuel)</th>
<th>NO (g/kg dry fuel)</th>
<th>SO$_2$ (g/kg dry fuel)</th>
<th>CO (g/kg dry fuel)</th>
<th>Particles (g/kg dry fuel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UIE, 6$^{th}$ July 2006</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3.79</td>
</tr>
<tr>
<td>UIE, 23$^{rd}$ December 2006</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4.83</td>
</tr>
<tr>
<td>Jendarata, 24$^{th}$ May 2006</td>
<td>0.0124*</td>
<td>0.692</td>
<td>0.0173*</td>
<td>0.621</td>
<td>1.61</td>
</tr>
<tr>
<td>Jendarata, 13$^{rd}$ June 2006</td>
<td>-</td>
<td>1.13</td>
<td>0.0408</td>
<td>-</td>
<td>1.06</td>
</tr>
<tr>
<td>Ulu Bernam, 28$^{th}$ March 2006</td>
<td>-</td>
<td>1.02</td>
<td>-</td>
<td>3.71</td>
<td>4.63</td>
</tr>
<tr>
<td>Ulu Bernam, 7$^{th}$ November 2006</td>
<td>-</td>
<td>1.49</td>
<td>-</td>
<td>3.06</td>
<td>2.97</td>
</tr>
<tr>
<td>Seri Pelangi, January 2006</td>
<td>0.170*</td>
<td>0.841</td>
<td>0.0215*</td>
<td>4.95</td>
<td>3.64</td>
</tr>
<tr>
<td>Seri Pelangi, July 2006</td>
<td>0.0113*</td>
<td>2.15</td>
<td>0.0157*</td>
<td>1.88</td>
<td>3.44</td>
</tr>
</tbody>
</table>

| Applied: Conventional UP mills   | 3.60                   | 3.88               |
| Applied: Jendarata              | 0.0646                 | 1.25               | 0.0238                 | 0.62              | 1.34                       |
| Applied: Average UP mills (83% conventional and 17% Jendarata) | 3.09                   | 3.45               |

| Burning of wood chips           | 2.10                   | 0.0473             | 2.23                   | 0.643             |

Schmidt (2008), Life cycle assessment of palm oil at United Plantations Berhad. United Plantations Berhad
Programme

• Goal and scope
• System boundaries
• Life cycle inventory: critical emissions

• LCA-results: palm oil and improvement options
Overview of differences between aver Malaysia and United Plantations

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Malaysia aver.</th>
<th>Mineral soil</th>
<th>Peat soil</th>
<th>United Plantations Berhad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield</td>
<td>17.0 t FFB/ha yr</td>
<td>17.1 t FFB/ha yr</td>
<td>16.2 t FFB/ha yr</td>
<td>24.0 t FFB/ha yr</td>
</tr>
<tr>
<td>Peat drainage depth</td>
<td>-</td>
<td>-</td>
<td>75 cm</td>
<td>60 cm</td>
</tr>
<tr>
<td>Oil extraction rate (oil per FFB)</td>
<td>0.20</td>
<td>-</td>
<td>-</td>
<td>0.21</td>
</tr>
<tr>
<td>Oil mills with biogas</td>
<td>0%</td>
<td>0%</td>
<td>-</td>
<td>16.5%</td>
</tr>
<tr>
<td>Oil mills with biomass plant</td>
<td>0%</td>
<td>0%</td>
<td>16.5%</td>
<td>16.5%</td>
</tr>
</tbody>
</table>

Schmidt (2008), Life cycle assessment of palm oil at United Plantations Berhad. United Plantations Berhad
Weighted results: Malaysian palm oil

Based on: Schmidt (2008), Life cycle assessment of palm oil at United Plantations Berhad. United Plantations Berhad
Process contribution: characterised results

- N$_2$O: 38%
- CO$_2$: 32%
- CH$_4$: 30%
- Other: <1%

- Particles: 75%
- NH$_3$: 12%
- NO$_x$: 11%
- Other: <2%

Based on: Schmidt (2008), Life cycle assessment of palm oil at United Plantations Berhad. United Plantations Berhad
Improvement options: GHG-emissions

Based on: Schmidt (2008), Life cycle assessment of palm oil at United Plantations Berhad. United Plantations Berhad
Combination of improvement options: GHG-emissions

Mineral soil UP: 13.4% peat
MY: 9.5% peat
Peat soil

Based on: Schmidt (2008), Life cycle assessment of palm oil at United Plantations Berhad. United Plantations Berhad
Improvement options: Respiratory inorganics

Based on: Schmidt (2008), Life cycle assessment of palm oil at United Plantations Berhad. United Plantations Berhad
## Land transformation: GHG-emissions

<table>
<thead>
<tr>
<th></th>
<th>From secondary/degraded forest to oil palm, Malaysia and Indonesia</th>
<th>From alang-alang grassland to oil palm, Malaysia and Indonesia</th>
<th>From cerrado savannah to soybean, Brazil</th>
<th>From secondary/degraded forest to soybean, Brazil</th>
<th>From prairie grassland to barley, Canada</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil palm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>415 t CO₂/ha</td>
<td>-33 t CO₂/ha</td>
<td>279 t CO₂/ha</td>
<td>752 t CO₂/ha</td>
<td>84 t CO₂/ha</td>
</tr>
<tr>
<td>N₂O</td>
<td>0.075 t N₂O/ha</td>
<td>0 t N₂O/ha</td>
<td>0.062 t N₂O/ha</td>
<td>0.147 t N₂O/ha</td>
<td>0.020 t N₂O/ha</td>
</tr>
<tr>
<td>Soybean</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N₂O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybean</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N₂O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barley</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N₂O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Assumption: Transformation supports cultivation in 100 years**

Schmidt (2008), Life cycle assessment of palm oil at United Plantations Berhad. United Plantations Berhad
Land transformation: GHG-emissions

Based on: Schmidt (2008), Life cycle assessment of palm oil at United Plantations Berhad. United Plantations Berhad
Concluding remarks

- Most significant impacts: GHG, land use, respiratory inorganics
- Most significant improvement potentials
  - Avoid cultivation of peat
  - Capture and utilise methane from POME
  - Increase yields by good management (replanting, fertiliser, integrated pest management) and good planting material
- Potential to reduce GHG emissions with factor 3-5!
Allocation – impossible processes are created
Unallocated milking cow (per 100 DM feed)

100 DM feed

\[ \Sigma \text{outputs} = 100 \]

- 9.3 Milk
- 2.2 Meat
- 2.0 CH\(_4\)
- 23.2 Manure
- 28.3 C in CO\(_2\)
- 35.0 respiratory water

Milk: 77% of turnover
Meat: 23% of turnover
Allocated milking cow (economic allocation: milk 77%)

77 DM feed

- 1.5 CH₄
- 17.9 Manure
- 21.8 C in CO₂
- 27.0 respiratory water

9.3 Milk  2.2 Meat

Milk: 77% of turnover
Meat: 23% of turnover

Σoutputs = 77.5
Functional unit = palm oil + palm kernel oil

Palm oil system

0.893 t veg. oil for food

0.107 t PKO

1 t veg. Oil for food

Uses: substitutable market segment

Special fat market segment
Marginal suppliers

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1000 t</td>
<td>1000 t</td>
<td>1000 t</td>
</tr>
<tr>
<td>Palm oil</td>
<td>Indonesia*</td>
<td>449</td>
<td>1,251</td>
<td>965</td>
</tr>
<tr>
<td></td>
<td>Malaysia*</td>
<td>598</td>
<td>840</td>
<td>552</td>
</tr>
<tr>
<td></td>
<td>Nigeria</td>
<td>17</td>
<td>57</td>
<td>No data</td>
</tr>
<tr>
<td>Soybean</td>
<td>Brazil*</td>
<td>1,819</td>
<td>4,037</td>
<td>3,535</td>
</tr>
<tr>
<td></td>
<td>Argentina</td>
<td>2,021</td>
<td>3,115</td>
<td>1,514</td>
</tr>
<tr>
<td></td>
<td>US</td>
<td>2,947</td>
<td>1,586</td>
<td>149</td>
</tr>
<tr>
<td>Barley</td>
<td>Canada*</td>
<td>-198</td>
<td>182</td>
<td>229</td>
</tr>
<tr>
<td></td>
<td>EU25</td>
<td>430</td>
<td>-443</td>
<td>181</td>
</tr>
<tr>
<td></td>
<td>Russia</td>
<td>-1,015</td>
<td>19</td>
<td>162</td>
</tr>
</tbody>
</table>

Marginal suppliers: Area or yield

<table>
<thead>
<tr>
<th>Crop</th>
<th>Growth by area and yield</th>
<th>Data source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil palm, Malaysia/Indonesia</td>
<td>Area: 96%</td>
<td>Yield: 4%</td>
</tr>
<tr>
<td>Soybean, Brazil</td>
<td>Area: 81%</td>
<td>Yield: 19%</td>
</tr>
<tr>
<td>Barley, Canada</td>
<td>Area: 69%</td>
<td>Yield: 31%</td>
</tr>
</tbody>
</table>