Life cycle assessment of pesticides

Birkved, Morten

Publication date: 2012

Citation (APA):

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.
Life cycle assessment of pesticides

The importance of reliable pesticide production and manufacturing unit process data for correct environmental profiling of pesticide life cycles.

Assistant professor Morten Birkved
Section of Quantitative Sustainability Assessment, QSA
Department of Management Engineering
Technical University of Denmark
Presentation outline

- Comparison of environmental risk assessment and life cycle impact assessment
- Life cycle impact assessment of pesticides
- Example 1 – Comparison of life cycle impact assessment profiles of 8 pesticides
- Example 2 – Comparison of life cycle impact assessment profiles of an older and a newer pesticide
- Example 3 - Comparison of life cycle impact assessment profiles of one pesticide relying on data from 2 different commercial sources
- Conclusions
Environmental assessment of products and services

Assessment of the environmental performance and impacts of products and services:
• Environmental Risk Assessment (ERA)
• Life Cycle Impact Assessment (LCIA)
• Cradle to Cradle (C2C)
• Cost Benefit Analysis (CBA)

Differences and common properties:
• Quantification of environmental ”burden” related with product or services
• Very different approaches:
  - Transparency
  - Goal, scope
  - Temporal & spatial boundaries

DTU Management Engineering
Department of Management Engineering
Focus of this presentation – ERA and LCIA in relation to pesticide evaluation

**ERA**

- Impact focused
- Few and local impacts
- Focuses *per se* on negative aspects (i.e. positive aspects are only acknowledged in terms of efficacy)

**LCIA**

- Impact focused
- Many and both local to global impacts
- Acknowledges trade-offs and hence both positive and negative assessment aspects
The life cycle of pesticides

Is the complete environmental burden of pesticides represented solely by the use stage of the pesticide life cycle?
Risk assessment of pesticides

Pesticide risk assessment focus points:

- Inherent toxicity of the pesticide product/active ingredient
- Inherent physical-chemical properties of pesticide product/active ingredient
- Environmental behavior of the pesticide product/active ingredient in the environment
- Efficacy of the pesticide product/active ingredient

Risk assessment – feedback to pesticide production/manufacturing link of the product system:

- Risk assessment are in most countries/regions required in order to obtain approval for use
- Risk assessment schemes/criteria are hence having strong influence on the environmental innovation of pesticides
- The use stage is thus having strong influence on the impacts of pesticides aggregated over the complete life cycle

Use stage related impact induced manufacturing demands

Diagram:

1. Extraction of raw materials
2. Production of process chemicals
3. Pesticide manufacturing
4. Use
5. (Disposal)

DTU Management Engineering
Department of Management Engineering
Risk and life cycle impact assessment of pesticides

Extraction of raw materials → Production of process chemicals → Pesticide manufacturing → Use → (Disposal)

LCIA – impacts aggregated over complete life cycle

Will orthogonal assessment methods yield different results?

DTU Management Engineering
Department of Management Engineering

M. Birkved
Informa – AgroChem
28.02 2012
LCIA

Quantification of impacts in a system perspective

A system perspective is needed to quantify the complete environmental performance of products and services;

- Adapting a life cycle perspective to avoid problem-shifting
- Considering all relevant types of impacts
- Addressing trade-offs between impacts (and sustainability dimensions)
The need for a systems perspective

DTU Management Engineering
Department of Management Engineering

Wang et al., 2011
Life cycle inventory analysis and unit processes
The building blocks of LCIA

THE PROCESS AS THE FUNDAMENTAL ELEMENT OF THE PRODUCT SYSTEM

DTU Management Engineering
Department of Management Engineering
Quantification of environmental impacts in LCIA

Throughout the life cycle, processes exchange substances and materials with the surroundings

- Resources and materials go in
- Products, emissions and waste go out

These exchanges have the potential to impact on the environment and contribute to the environmental problems

We have to study the environmental impacts throughout the life cycle
Environmental impacts considered in LCIA

From the *global*
- Greenhouse effect and climate change
- Degradation of stratospheric ozone
- Depletion of non-renewable resources

… over the *regional*
- Acidification
- Enrichment with nutrients
- Toxicity to ecosystems and humans
- Photochemical air pollution
Environmental impacts considered in LCIA

… to the local

• Clearing of land, loss of soil and habitats
• Depletion of water resources

The environmental impacts can be calculated for each exchange and expressed for/aggregated over the whole life cycle of the product.

A common metric for all environmental impacts is the Person equivalent, PE:

How large is the impact from the product compared to the annual environmental impact from an average person?
Inventory of environmental exchanges

<table>
<thead>
<tr>
<th>Substance</th>
<th>CAS.no.</th>
<th>to air</th>
<th>to water</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-hydroxy-ethanacrylate</td>
<td>816-61-0</td>
<td>0.0348</td>
<td></td>
</tr>
<tr>
<td>4,4-methylenebis cyclohexylamine</td>
<td>1761-71-2</td>
<td>5.9E-02</td>
<td></td>
</tr>
<tr>
<td>Ammonia</td>
<td>7664-81-7</td>
<td>3.7E-05</td>
<td>4.2E-05</td>
</tr>
<tr>
<td>Arsenic ( As )</td>
<td>7440-38-2</td>
<td>2.0E-05</td>
<td></td>
</tr>
<tr>
<td>Benzene</td>
<td>71-43-2</td>
<td>5.0E-02</td>
<td></td>
</tr>
<tr>
<td>Lead ( Pb )</td>
<td>7439-92-1</td>
<td>8.5E-06</td>
<td></td>
</tr>
<tr>
<td>Butylxethanol</td>
<td>111-76-2</td>
<td>6.6E-01</td>
<td></td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>124-38-9</td>
<td>2.6E+02</td>
<td></td>
</tr>
<tr>
<td>Carbonmonoxide ( CO )</td>
<td>630-08-0</td>
<td>1.9E-06</td>
<td></td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>7440-47-3</td>
<td>5.3E-06</td>
<td></td>
</tr>
<tr>
<td>Chlorine ( Cl2 )</td>
<td>7782-50-5</td>
<td>4.6E-06</td>
<td></td>
</tr>
<tr>
<td>Chromium ( Cr VI )</td>
<td>7440-47-3</td>
<td>5.3E-06</td>
<td></td>
</tr>
<tr>
<td>Dicyclohexane methane</td>
<td>86-73-6</td>
<td>5.1E-02</td>
<td></td>
</tr>
<tr>
<td>Nitrous oxide( N2O )</td>
<td>10024-97-2</td>
<td>1.7E-02</td>
<td></td>
</tr>
<tr>
<td>2,4-Dinitrotoluene</td>
<td>121-14-2</td>
<td>5.0E-02</td>
<td></td>
</tr>
<tr>
<td>HMDI</td>
<td>5124-30-1</td>
<td>7.5E-02</td>
<td></td>
</tr>
<tr>
<td>Hydro carbons (electricity, stationary combusting)</td>
<td>-</td>
<td>1.0E-03</td>
<td></td>
</tr>
<tr>
<td>i-butanol</td>
<td>78-83-1</td>
<td>3.5E-02</td>
<td></td>
</tr>
<tr>
<td>i-propanol</td>
<td>67-63-0</td>
<td>9.2E-01</td>
<td></td>
</tr>
<tr>
<td>Copper ( Cu )</td>
<td>7740-50-8</td>
<td>1.8E-05</td>
<td></td>
</tr>
<tr>
<td>Hydrogen ions (H+)</td>
<td>-</td>
<td>1.0E-03</td>
<td></td>
</tr>
<tr>
<td>Methyl i-butyl ketone</td>
<td>108-10-1</td>
<td>5.7E-02</td>
<td></td>
</tr>
<tr>
<td>Monochloro acetic acid</td>
<td>75-04-7</td>
<td>7.9E-06</td>
<td></td>
</tr>
<tr>
<td>Nickel ( Ni )</td>
<td>7440-02-0</td>
<td>1.1E-05</td>
<td></td>
</tr>
<tr>
<td>Nitrogen oxide ( NOx )</td>
<td>10102-44-0</td>
<td>1.1E-00</td>
<td></td>
</tr>
<tr>
<td>NMVOC, diesel engines (exhaust)</td>
<td>-</td>
<td>3.9E-02</td>
<td></td>
</tr>
<tr>
<td>NMVOC, power plants (stationary combustion)</td>
<td>-</td>
<td>3.9E-03</td>
<td></td>
</tr>
<tr>
<td>Ozone ( Oz )</td>
<td>10028-15-6</td>
<td>1.8E-03</td>
<td></td>
</tr>
<tr>
<td>PAH</td>
<td>-</td>
<td>2.4E-08</td>
<td></td>
</tr>
<tr>
<td>Phenol</td>
<td>108-95-2</td>
<td>1.3E-05</td>
<td></td>
</tr>
<tr>
<td>Phosgene</td>
<td>75-44-5</td>
<td>1.4E-01</td>
<td></td>
</tr>
<tr>
<td>Polyether polyol</td>
<td>-</td>
<td>1.6E-01</td>
<td></td>
</tr>
<tr>
<td>1,2-propyleneoxide</td>
<td>75-56-9</td>
<td>8.2E-02</td>
<td></td>
</tr>
<tr>
<td>Nitric acid</td>
<td>7782-77-9</td>
<td>8.5E-02</td>
<td></td>
</tr>
<tr>
<td>Hydrochloric acid</td>
<td>7647-01-0</td>
<td>1.9E-03</td>
<td></td>
</tr>
<tr>
<td>Selenium ( Se )</td>
<td>7782-49-2</td>
<td>2.6E-05</td>
<td></td>
</tr>
<tr>
<td>Sulphur dioxide(SO2 )</td>
<td>7446-09-5</td>
<td>1.3E-00</td>
<td></td>
</tr>
<tr>
<td>Toluene</td>
<td>108-88-3</td>
<td>4.8E-02</td>
<td></td>
</tr>
<tr>
<td>Toluene-2,4-diamine</td>
<td>95-80-7</td>
<td>7.9E-02</td>
<td></td>
</tr>
<tr>
<td>Toluene diisocyanate (TDI)</td>
<td>26471-62-6</td>
<td>1.6E-01</td>
<td></td>
</tr>
<tr>
<td>Total-N</td>
<td>-</td>
<td>2.6E-05</td>
<td></td>
</tr>
<tr>
<td>Triethylamine</td>
<td>121-44-8</td>
<td>1.6E-01</td>
<td></td>
</tr>
<tr>
<td>Unspecified aldehydes</td>
<td>-</td>
<td>3.5E-04</td>
<td></td>
</tr>
<tr>
<td>Unspecified organic compounds</td>
<td>-</td>
<td>1.5E-03</td>
<td></td>
</tr>
<tr>
<td>Vanadium</td>
<td>7440-62-2</td>
<td>1.8E-04</td>
<td></td>
</tr>
<tr>
<td>VOC, diesel engines (exhaust)</td>
<td>-</td>
<td>6.4E-05</td>
<td></td>
</tr>
<tr>
<td>VOC, stationary combustion (coal fired)</td>
<td>-</td>
<td>4.6E-05</td>
<td></td>
</tr>
<tr>
<td>VOC, stationary combustion (natural gas fired)</td>
<td>-</td>
<td>2.2E-03</td>
<td></td>
</tr>
<tr>
<td>VOC, stationary combustion (oil fired)</td>
<td>-</td>
<td>1.4E-04</td>
<td></td>
</tr>
<tr>
<td>Xylene</td>
<td>1330-20-7</td>
<td>1.4E-01</td>
<td></td>
</tr>
<tr>
<td>Zinc ( Zn )</td>
<td>7469-66-6</td>
<td>8.8E-05</td>
<td></td>
</tr>
</tbody>
</table>

LCIA – in practise

Analysed system (life cycle)

Environmental profile of solutions

- Global warming
- Acidification
- Photochemical ozone formation
- Nutrient enrichment
- Human toxicity
- Ecotoxicity
- Land use
- Volume waste
- Hazardous waste

LCIA
Life Cycle Assessment – an ISO standardized approach

ISO 14040

ISO 14021-25
ISO TR14062, etc.

Goal & scope
definition

Inventory
analysis

Impact
assessment

Interpretation

Direct application
e.g. product development
marketing
ecolabelling
public policy making

ISO 14044
Characterization of chemical emissions in LCIA

As in ERA, quantification of toxicological impacts resulting from chemical emissions in LCIA involves two crucial steps:

• Quantification of emission masses (i.e. emissions to air, water, soil and ground water)
• Quantification of toxicological impacts from chemical emissions

Both aspects are in LCIA covered by models similar to those applied in ERA:

• Quantification of pesticide emissions – e.g. PestLCI
• Quantification of toxicological impacts – e.g. USEtox™ (UNEP/SETAC)
Quantification of pesticide emissions in LCA PestLCI

Basic Model setup:
Field modeled as part of technosphere from which emissions occur

Model output:
Mission fractions to
• Air
• Water
• Soil
• Ground water

From Dijkman et al. 2012
Quantification of toxicological impacts from chemicals in LCIA - USEtox™

Basic Model setup:
Emission compartment specific fate and exposure modeling enabling assessment of human and eco-toxicological impact potentials

From Huijbregts et al. 2010
Pesticide LCIA – example of life cycle impact assessment and use stage impact assessment of pesticides – example 1

8 Pesticides (eco-invent 2.2.)
- Carbofuran
- Diuron
- Glyphosate
- Linuron
- MCPA
- Metolachlor
- Parathion
- Propachlor

Data needed
- Cradle to gate inventories for quantification of production/manufacturing related emissions
- Characterization factors for the a.i. for quantification of use related impacts AND characterization factors for all other emissions occurring from cradle to gate
Pesticide impact quantification – example 1

Impacts contributions considered in examples

**Common LCIA/ERA impact indicators considered**

- Human toxicity potential
- Terrestrial ecotoxicity potential
- Freshwater aquatic ecotoxicity potential
- Marine aquatic ecotoxicity potentials
Pesticide life cycle impacts – example 1

<table>
<thead>
<tr>
<th>Pesticide</th>
<th>Extraction of raw materials</th>
<th>Production of process chemicals</th>
<th>Pesticide manufacturing</th>
<th>Use</th>
<th>(Disposal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbofuran</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diuron</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glyphosate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linuron</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MCPA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metolachlor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parathion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Propachlor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Impacts distribution

<table>
<thead>
<tr>
<th>Pesticide</th>
<th>Total</th>
<th>Production</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbofuran</td>
<td>2.4×10⁻¹⁰</td>
<td>2.2×10⁻¹⁰</td>
<td>2.5×10⁻¹¹</td>
</tr>
<tr>
<td>Diuron</td>
<td>2.1×10⁻⁹</td>
<td>1.1×10⁻¹⁰</td>
<td>2.0×10⁻⁹</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>3.2×10⁻¹⁰</td>
<td>2.6×10⁻¹⁰</td>
<td>5.5×10⁻¹¹</td>
</tr>
<tr>
<td>Linuron</td>
<td>8.5×10⁻⁹</td>
<td>1.1×10⁻¹⁰</td>
<td>8.4×10⁻⁹</td>
</tr>
<tr>
<td>MCPA</td>
<td>6.5×10⁻¹¹</td>
<td>6.4×10⁻¹¹</td>
<td>2.2×10⁻¹³</td>
</tr>
<tr>
<td>Metolachlor</td>
<td>2.0×10⁻¹⁰</td>
<td>1.3×10⁻¹⁰</td>
<td>7.0×10⁻¹¹</td>
</tr>
<tr>
<td>Parathion</td>
<td>2.4×10⁻⁸</td>
<td>7.1×10⁻¹¹</td>
<td>2.4×10⁻⁸</td>
</tr>
<tr>
<td>Propachlor</td>
<td>1.4×10⁻¹⁰</td>
<td>1.4×10⁻¹⁰</td>
<td>3.5×10⁻¹²</td>
</tr>
</tbody>
</table>

Production related impacts + Use related impacts = Total
Overview of aggregated life cycle impacts of pesticides – example 1

Unit process origin: eco-invent 2.2

Quantification of emissions: PestLCI 2.0
Dijkman et al. 2012

Characterization method: CML2001

Normalization: CML2001-EU15:

Weighting: EU15
Stranddorff et al. 2005
Distribution of aggregated life cycle impacts of pesticides – example 1
Other studies on whole life cycle/use stage impacts of pesticides – example 2

Comparison *use* stage related impacts from chlorocholine and trinexapac-ethyl

From Geisler et al. (2005)
Other studies on whole life cycle/use stage impacts of pesticides – example 2

Comparison of life cycle related impacts from chlorocholine and trinexapac-ethyl

- Chlorocholine and trinexapac-ethyl were marketed 3 decades apart (1960s and 1990)
- Serve same functional unit (i.e. corrected for growth regulation efficacy)

The aggregated life cycle impacts of trinexapac-ethyl are not lower than those of chlorocholine (per functional unit)

- Trinexapac-ethyl is more resource/energy demanding and complex to manufacture than chlorocholine
- Impacts related with increased resource/energy demand in the cradle-to-gate steps of trinexapac-ethyl’s life cycle compensates for “avoided” toxicological impacts in the use stage
- Excellent example of problem shifting (burden shift from use stage to production and manufacturing)
### Uncertainties related with pesticide impact quantification in LCA – data origin – example 3

#### Magnitude of cradle-to-gate uncertainties

<table>
<thead>
<tr>
<th>Pesticide</th>
<th>Impact distribution</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Cradle-to-gate</td>
<td>Use</td>
<td></td>
</tr>
<tr>
<td>Pesticide</td>
<td>PEW&lt;sub&gt;EU15&lt;/sub&gt;</td>
<td>PEW&lt;sub&gt;EU15&lt;/sub&gt;</td>
<td>PEW&lt;sub&gt;EU15&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>Carbofuran (eco-invent 2.2)</td>
<td>2.4×10&lt;sup&gt;-10&lt;/sup&gt;</td>
<td>2.2×10&lt;sup&gt;-10&lt;/sup&gt;</td>
<td>2.5×10&lt;sup&gt;-11&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Carbofuran (PE)</td>
<td>6.1×10&lt;sup&gt;-11&lt;/sup&gt;</td>
<td>3.7×10&lt;sup&gt;-11&lt;/sup&gt;</td>
<td>2.5×10&lt;sup&gt;-11&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Ratio (eco-invent/PE)</td>
<td>3.9</td>
<td>5.9</td>
<td>1.0</td>
<td></td>
</tr>
</tbody>
</table>
Uncertainties related with pesticide impact quantification in LCA – example 3

Magnitude of cradle-to-gate uncertainties
Conclusions I

- Pesticide risk assessment focuses on one life cycle stage only, the use stage, and few environmental impact indicators (mainly toxic impacts)

- Pesticide risk assessment is having considerable influence on the performance of pesticides in the environmental dimension, and hence mainly one life cycle stage influences the overall environmental performance of pesticides

- Some pesticides exhibit use stage dominated aggregated life cycle impact profiles while other pesticides exhibit manufacturing dominated aggregated life cycle impact profiles

- Focusing solely on the use stage related impacts may thus lead to environmental burden shifting and hence sub-optimized pesticide life cycle impact profiles – i.e. system perspective needed
Conclusions II

• Newer/modern pesticides tend to have less impacts related with the use stage compared to older pesticides (i.e. effective toxic effect regulation of the use stage by ERA demand) (example 2)

• The indications are that newer/modern pesticides are more resource demanding to produce and manufacture than older pesticides and hence relatively more impacts are associated with the cradle-to-gate life cycle steps of newer/modern pesticides (example 2)

• Different inventory data sources yield different aggregated life cycle impact profiles for the same pesticide (example 3) – which influences the accuracy of LCAs of a vast number of agricultural products

• To assess and optimize the aggregated pesticide life cycle impacts appropriately, more and more consistent inventory data of the pesticide life stages from cradle-to-gate are needed
References


DTU Management Engineering
Department of Management Engineering