Technical University of Denmark

Life cycle assessment of pesticides

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Life cycle assessment of pesticides

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

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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

  ….

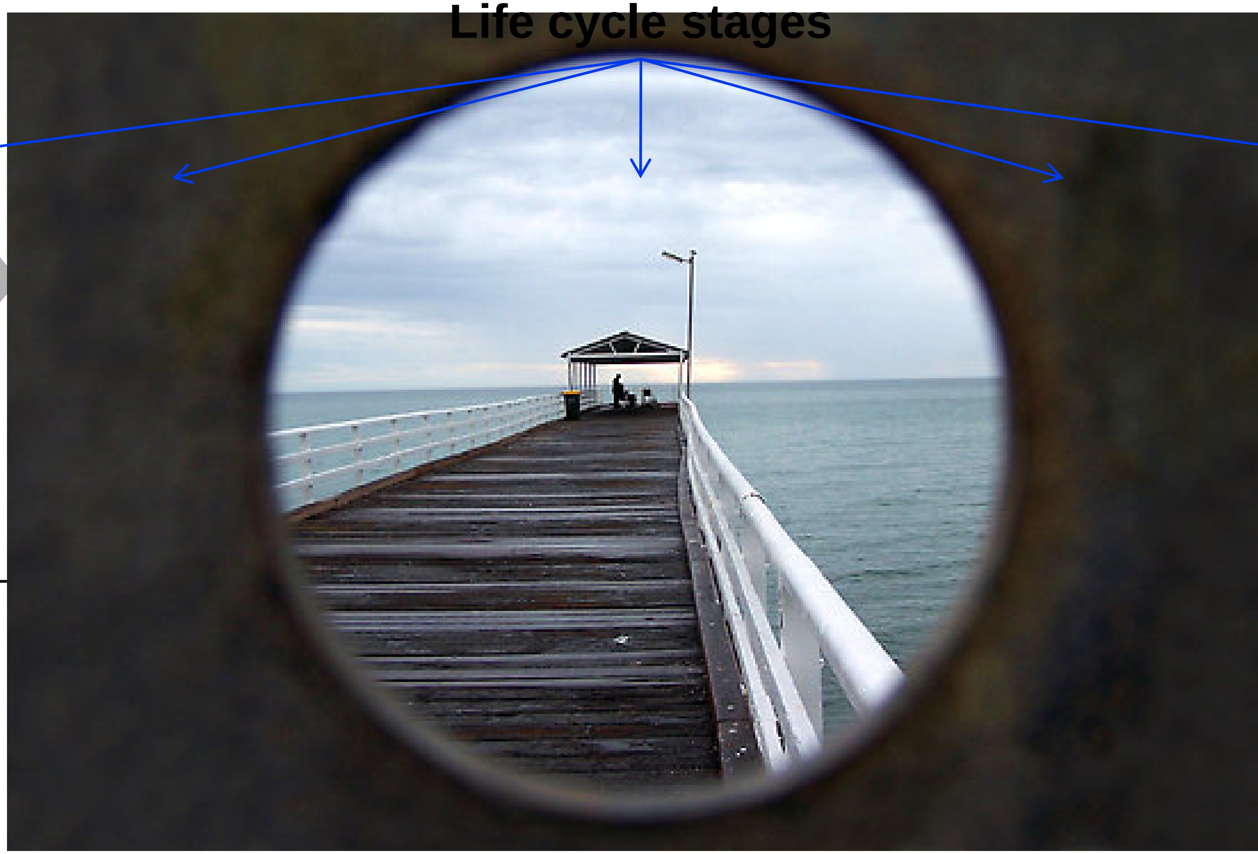
Focus of this presentation – ERA and LCIA in relation to pesticide evaluation

ERA	LCIA
• Impact focused	• Impact focused
• Few and local impacts	• Many and both local to global impacts
• Focuses *per se* on negative aspects (i.e. positive aspects are only acknowledged in terms of efficacy)	• Acknowledges trade-offs and hence both positive and negative assessment aspects

The life cycle of pesticides

Life cycle stages

Extraction of raw materials



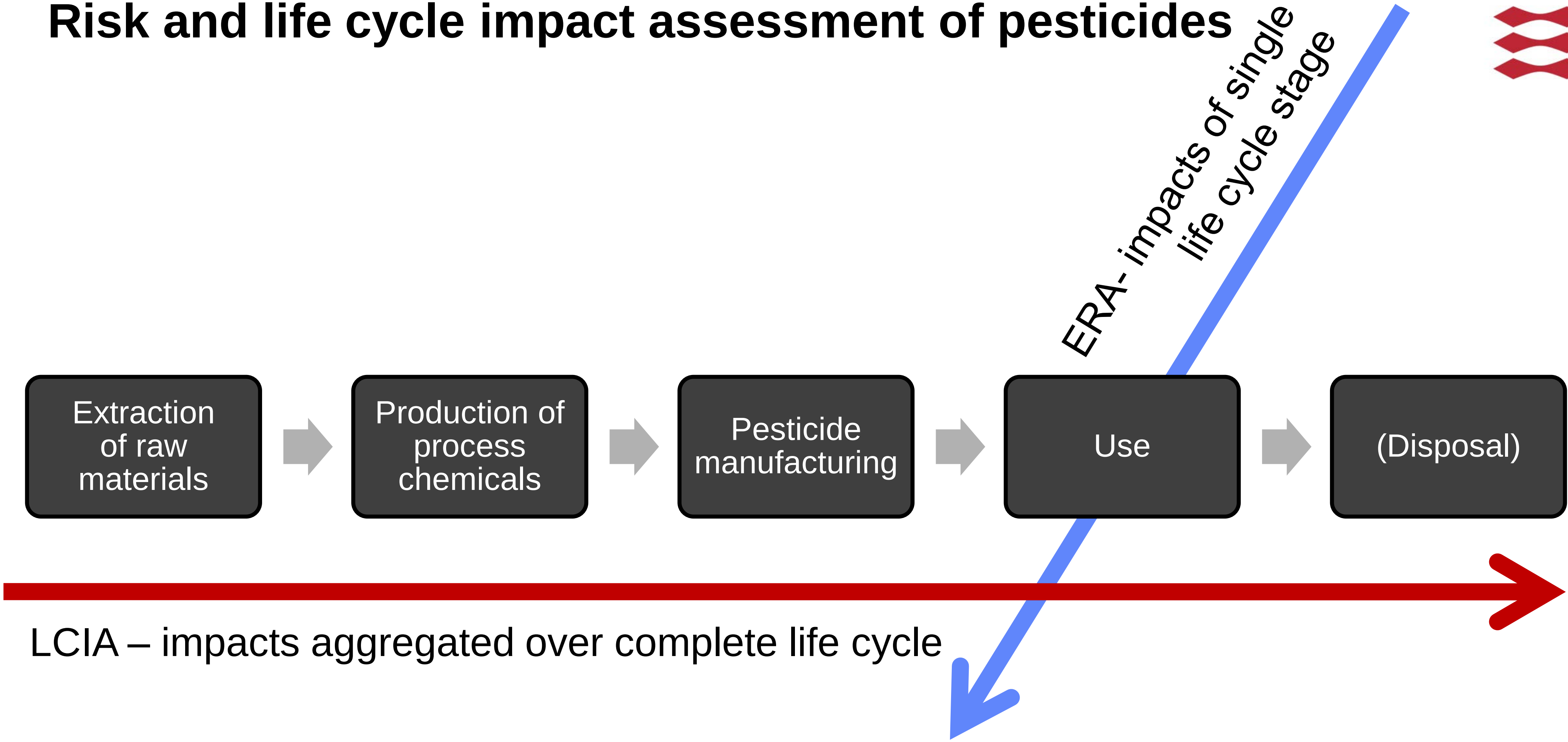
(Disposal)

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

Risk assessment of pesticides

Use stage related impact induced manufacturing demands

Risk and life cycle impact assessment of pesticides



Will orthogonal assessment methods yield different results?

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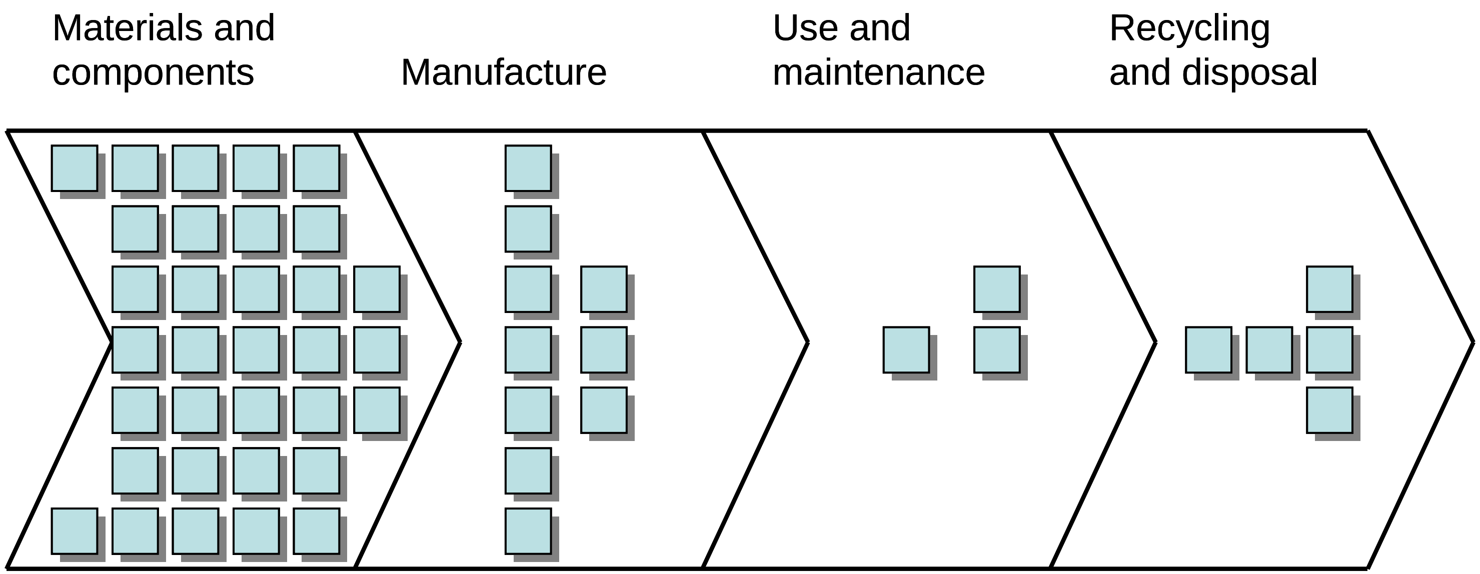
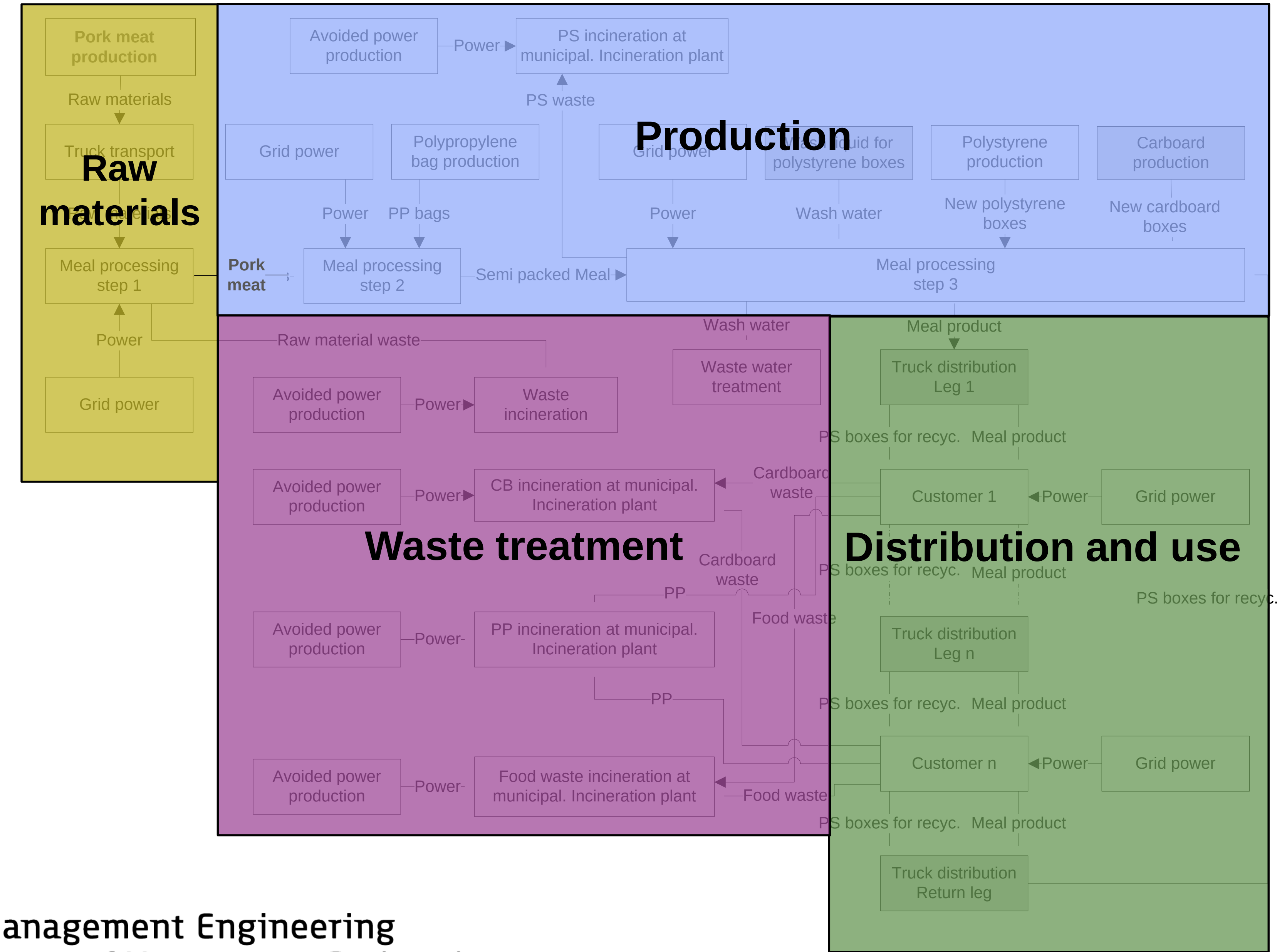
LCIA
Quantification of impacts in a system perspective



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

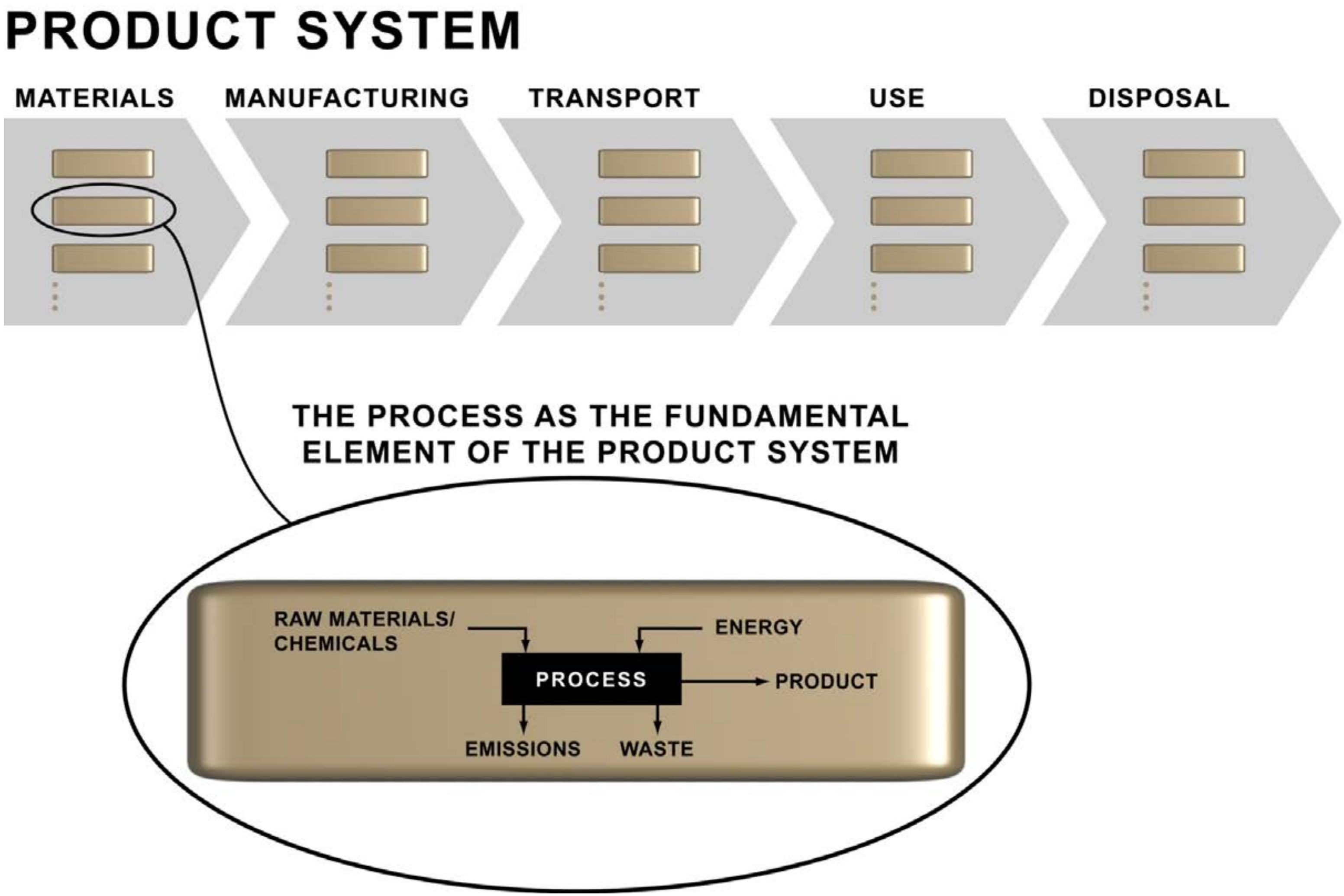
- Adapting a life cycle perspective to avoid problem-shifting
- Considering all relevant types of impacts
- Addressing trade-offs between impacts (and sustainability dimensions)

The need for a systems perspective



Wang et al., 2011

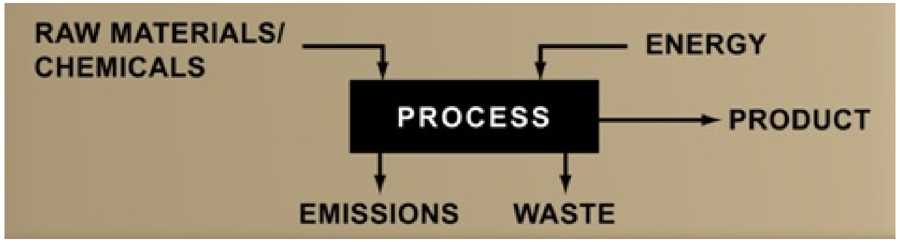
Life cycle inventory analysis and unit processes
The building blocks of LCIA



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



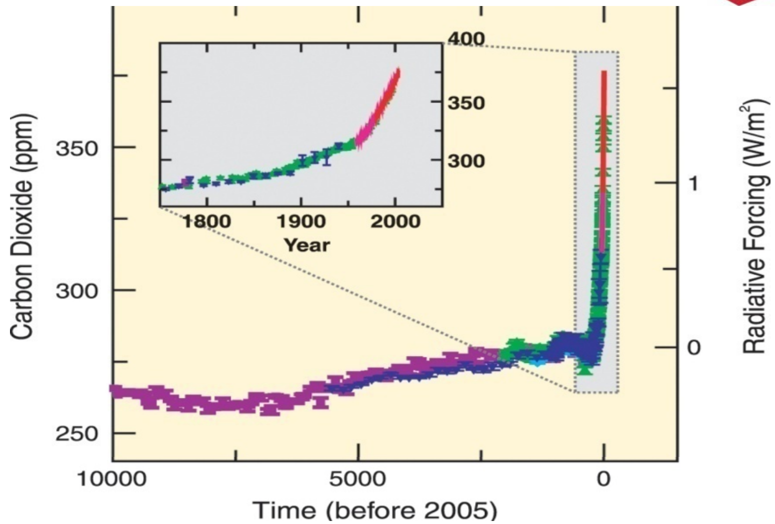
These exchanges have the potential to impact on the environment and contribute to the environmental problems

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***?

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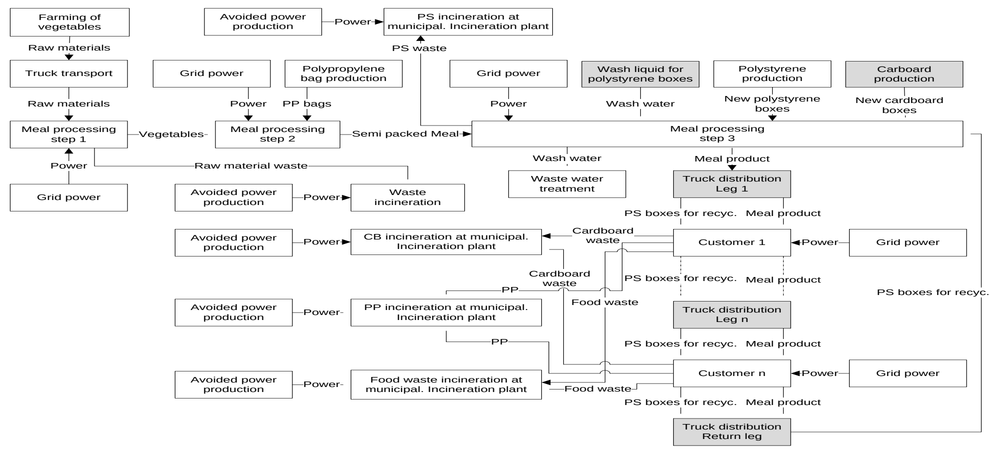
LCIA – in practise

Inventory of environmental exchanges

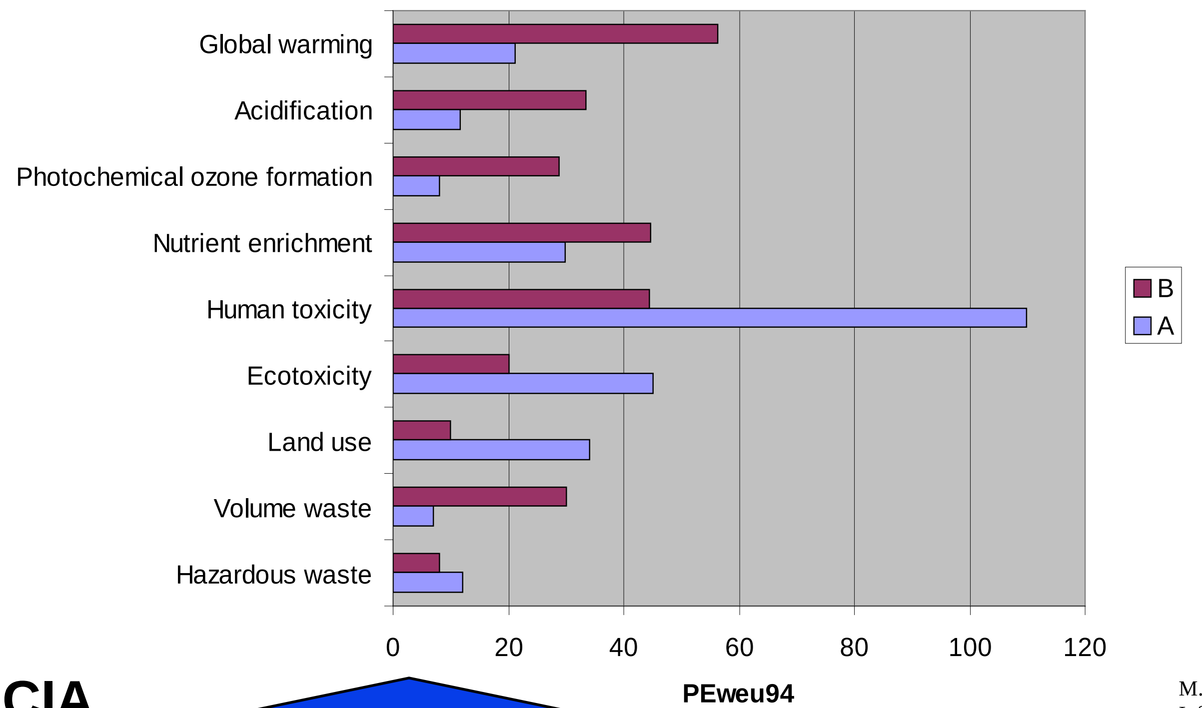
		Emission	Emission
	CAS.no.	to air	to w ater
Substance		g	g
2-hydroxy-ethanacrylate	816-61-0	0,0348	
4,4-methylenebis cyclohexylamine	1761-71-2	5,9E-02	
Ammonia	7664-81-7	3,7E-05	4,2E-05
Arsenic (As)	7440-38-2	2,0E-06	
Benzene	71-43-2 (cur	5,0E-02	
Lead (Pb)	7439-92-1	8,5E-06	
Butoxyethanol	111-76-2	6,6E-01	
Carbondioxide	124-38-9	2,6E+02	
Carbonmonoxide (CO)	630-08-0	1,9E-01	
Cadmium (Cd)	7440-46-9	2,2E-07	
Chlorine (Cl2)	7782-50-5	4,6E-04	
Chromium (Cr VI)	7440-47-3	5,3E-06	
Dicyclohexane methane	86-73-6	5,1E-02	
Nitrous oxide(N2O)	10024-97-2	1,7E-02	
2,4-Dinitrotoluene	121-14-2	9,5E-02	
HMDI	5124-30-1	7,5E-02	
Hydro carbons (electricity, stationary combustic	-	1,7E+00	
Hydrogen ions (H+)	-		1,0E-03
i-butanol	78-83-1	3,5E-02	
i-propanol	67-63-0	9,2E-01	
copper (Cu)	7740-50-8	1,8E-05	
Mercury(Hg)	7439-97-6	2,7E-06	
Methane	74-82-8	5,0E-03	
Methyl i-butyl ketone	108-10-1	5,7E-02	
Monoethyl amine	75-04-7		7,9E-06
Nickel (Ni)	7440-02-0	1,1E-05	
Nitrogen oxide (NOx)	10102-44-0	1,1E+00	
NMVOC, diesel engine (exhaust)	-	3,9E-02	
NMVOC, pow er plants (stationary combustion)	-	3,9E-03	
Ozone (O3)	10028-15-6	1,8E-03	
PAH	ikke specifik	2,4E-08	
Phenol	108-95-2		1,3E-05
Phosgene	75-44-5	1,4E-01	
Polyeter polyol	ikke specifik	1,6E-01	
1,2-propylenoxide	75-56-9	8,2E-02	
Nitric acid	7782-77-6 (c	8,5E-02	
Hydrochloric acid	7647-01-0 (c	1,9E-02	
Selenium (Se)	7782-49-2	2,6E-05	
Sulphur dioxide(SO2)	7446-09-5	1,3E+00	
Toluene	108-88-3	4,8E-02	
Toluene-2,4-diamine	95-80-7	7,9E-02	
Toluene diisocyanat (TDI)	26471-62-5	1,6E-01	
Total-N	-		2,6E-05
Triethylamine	121-44-8	1,6E-01	
Unspecified aldehydes	-	7,5E-04	
Uspecified organic compounds	-	1,5E-03	
Vanadium	7440-62-2	1,8E-04	
VOC, diesel engine (exhaust)	-	6,4E-05	
VOC, stationary combustion (coal fired)	-	4,0E-05	
VOC, stationary combustion (natural gas fired)	-	2,2E-03	
VOC, stationary combustion (oil fired)	-	1,4E-04	
Xylene	1330-20-7	1,4E-01	
Zinc (Zn)	7440-66-6	8,9E-05	

LCI

Analysed system (life cycle)



Environmental profile of solutions



LCIA

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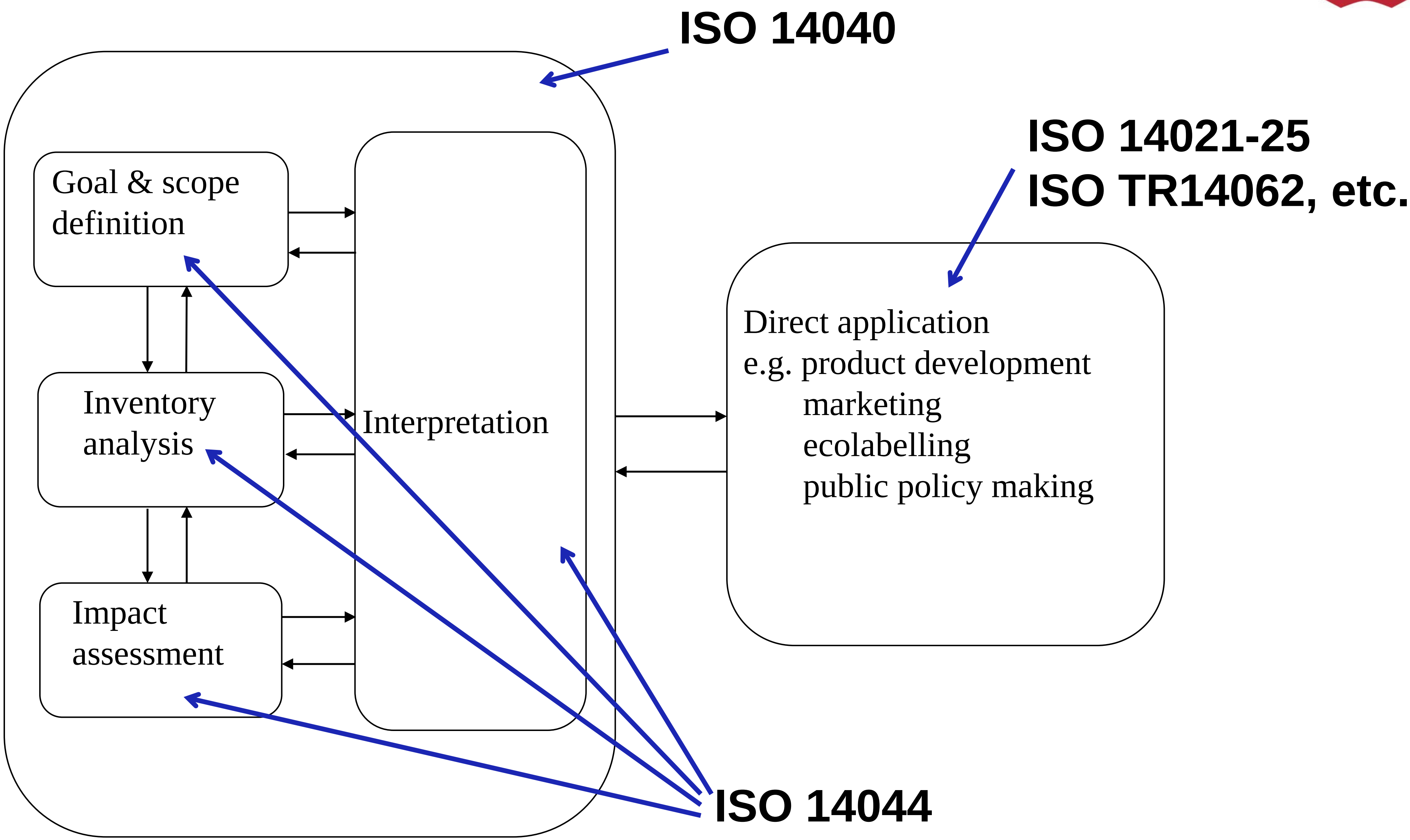
Life Cycle Assessment – an ISO standardized approach



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Characterization of chemical emissions in LCIA

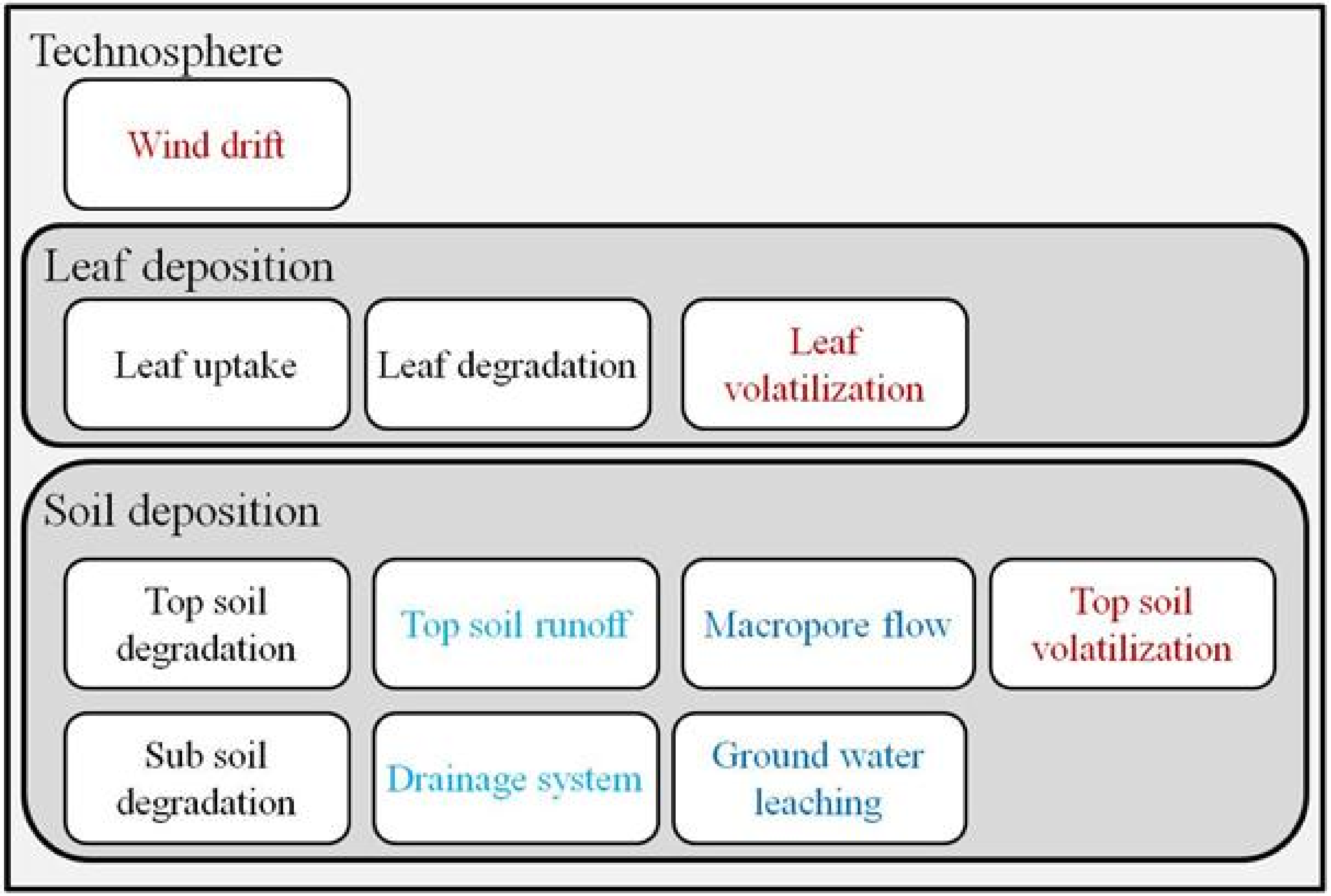
As in ERA, quantification of toxicological impacts resulting from chemical emissions in LCIA involves two crucial steps:

- 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^{TM} (UNEP/SETAC)

Quantification of pesticide emissions in LCA PestLCI

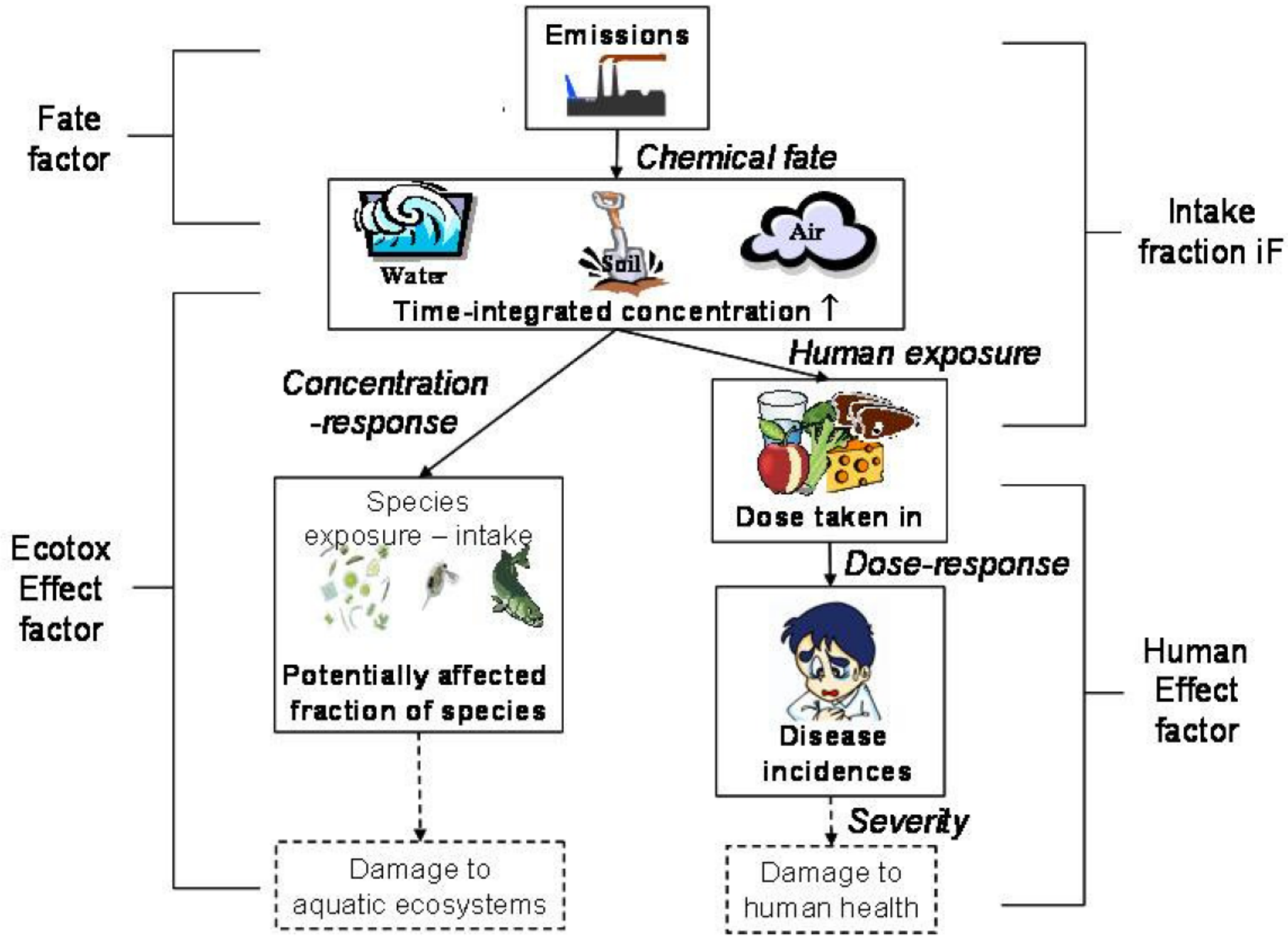


From Dijkman et al. 2012

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

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

Quantification of toxicological impacts from chemicals in LCIA - USEtox™



From Huijbregts et al. 2010

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

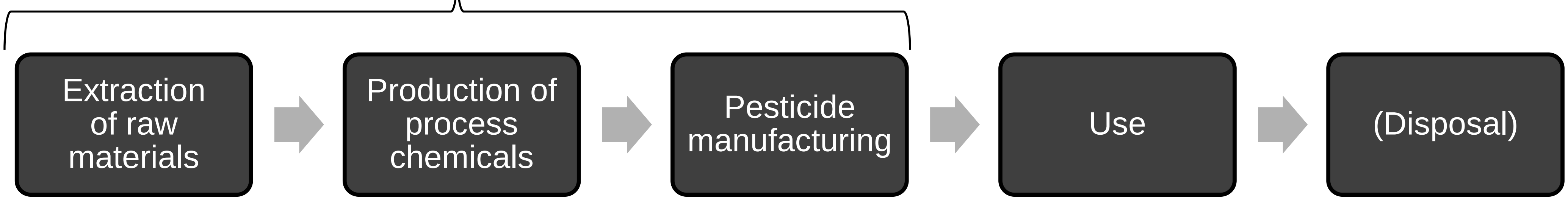
Pesticide LCIA – example of life cycle impact assessment and use stage impact assessment of pesticides – example 1

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

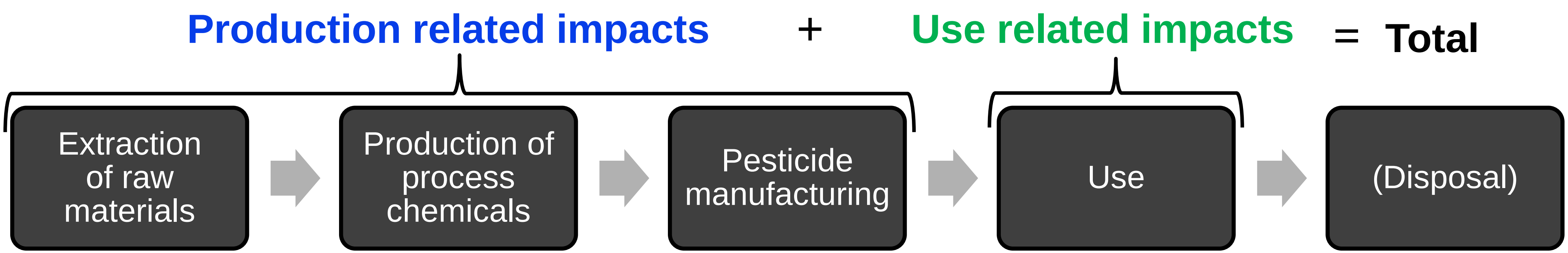
Impacts contributions considered in examples

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

	Impacts distribution		
	Total	Production	Use
Pesticide	PEW_{EU15}	PEW_{EU15}	PEW_{EU15}
Carbofuran	2.4×10^{-10}	2.2×10^{-10}	2.5×10^{-11}
Diuron	2.1×10^{-9}	1.1×10^{-10}	2.0×10^{-9}
Glyphosate	3.2×10^{-10}	2.6×10^{-10}	5.5×10^{-11}
Linuron	8.5×10^{-9}	1.1×10^{-10}	8.4×10^{-9}
MCPA	6.5×10^{-11}	6.4×10^{-11}	2.2×10^{-13}
Metolachlor	2.0×10^{-10}	1.3×10^{-10}	7.0×10^{-11}
Parathion	2.4×10^{-8}	7.1×10^{-11}	2.4×10^{-8}
Propachlor	1.4×10^{-10}	1.4×10^{-10}	3.5×10^{-12}



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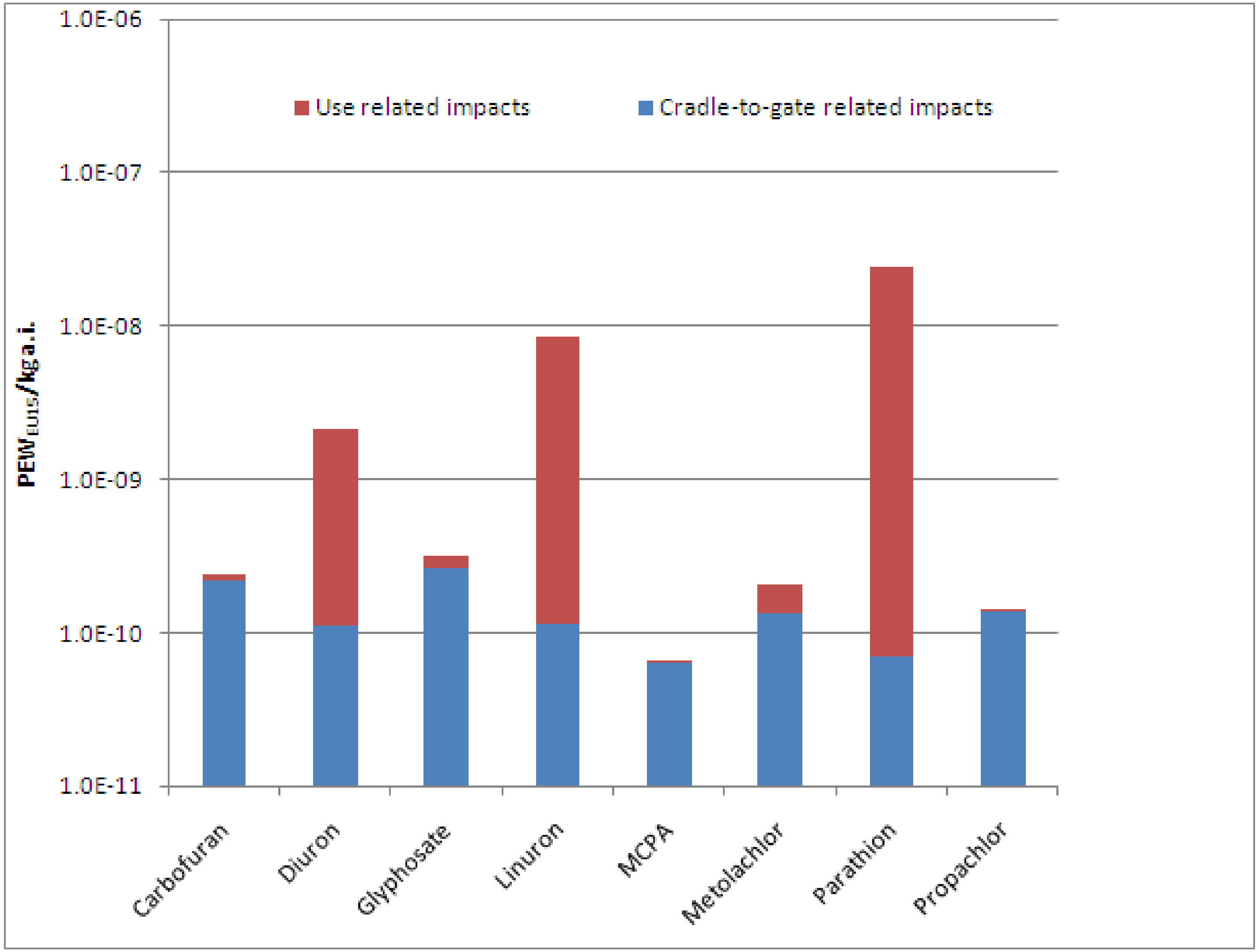
Overview of aggregated life cycle impacts of pesticides – example 1



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
Stranddorf et al. 2005

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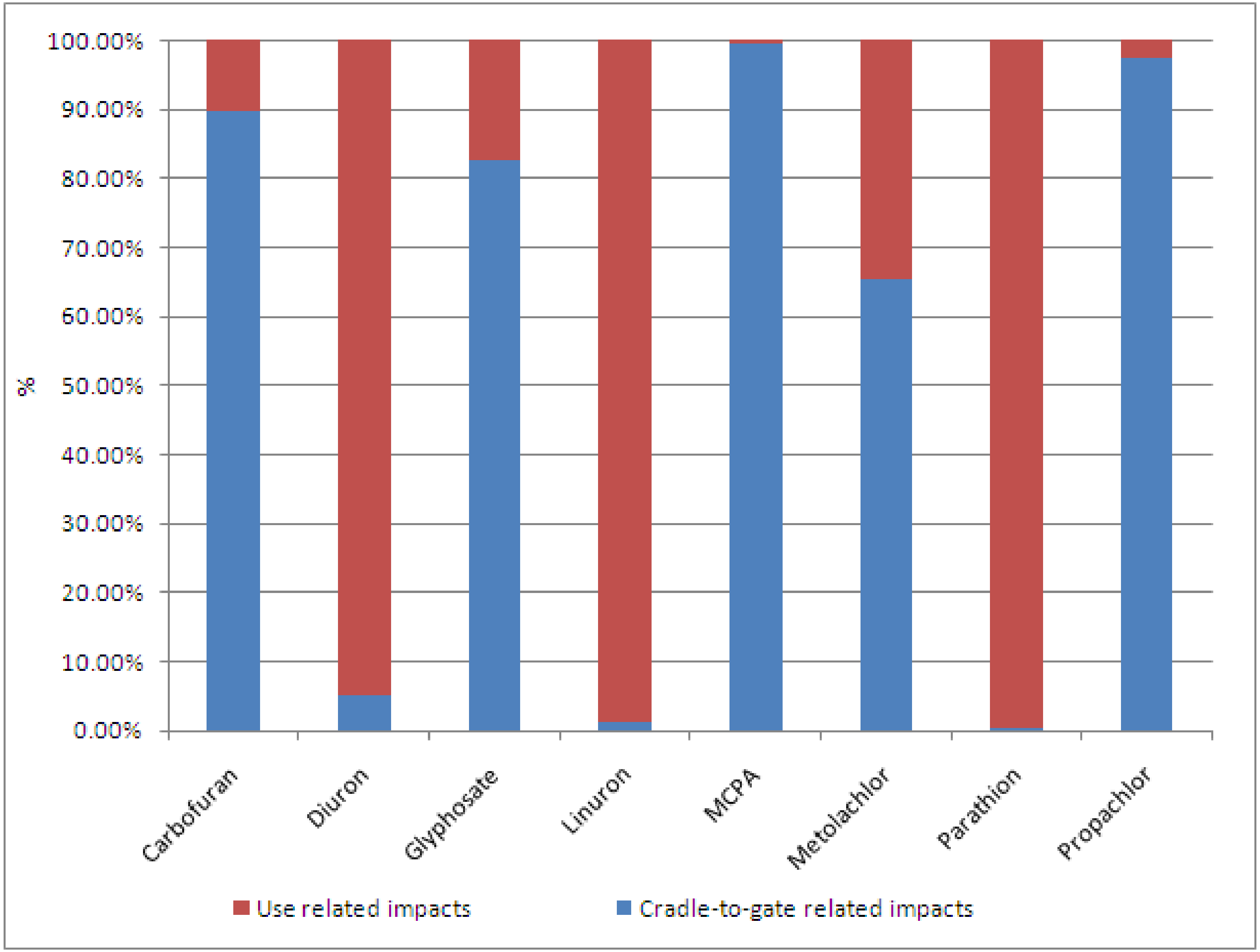
Distribution of aggregated life cycle impacts of pesticides – example 1



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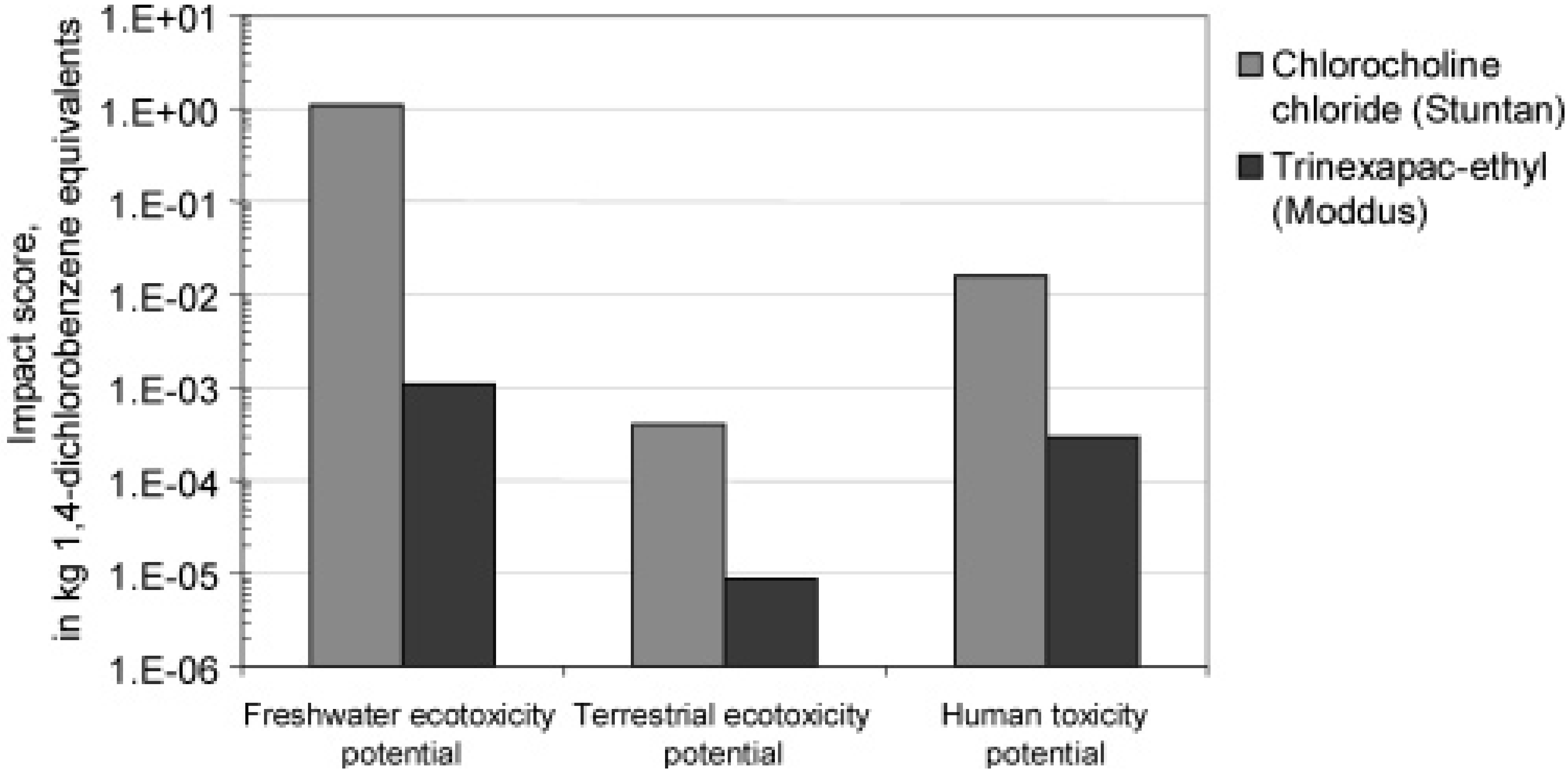
Other studies on whole life cycle/use stage impacts of pesticides – example 2

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

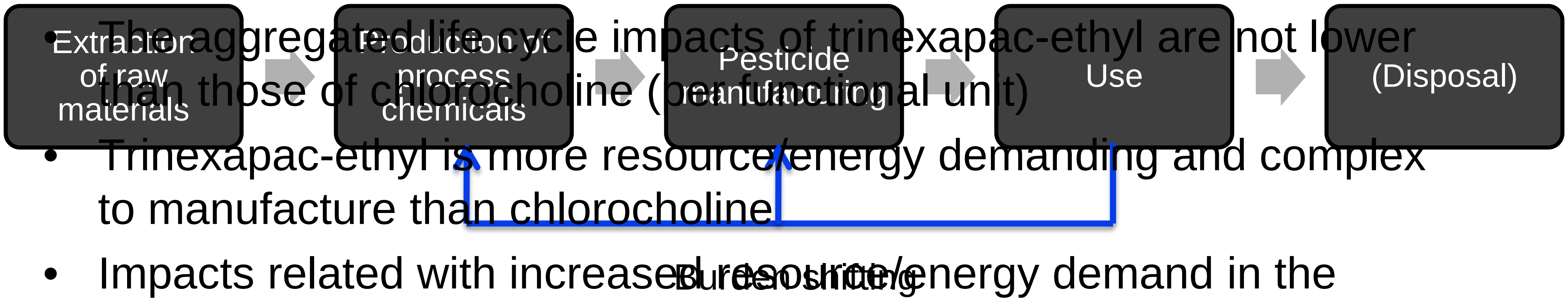


From Geisler et al. (2005)

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)

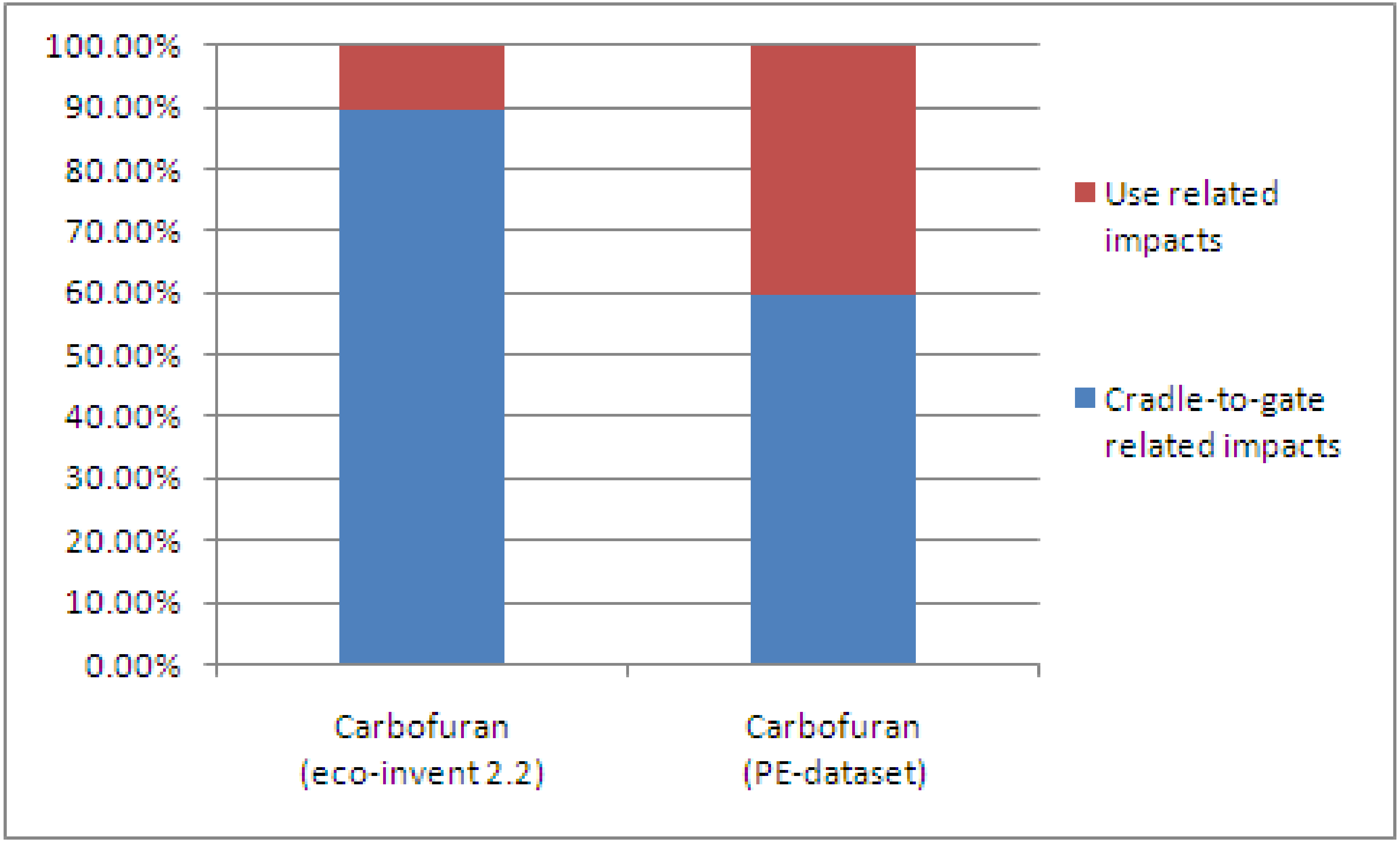
Uncertainties related with pesticide impact quantification in LCA – data origin – example 3

Magnitude of cradle-to-gate uncertainties

	Impact distribution		
	Total	Cradle-to-gate	Use
Pesticide	**PEW_{EU15}**	**PEW_{EU15}**	**PEW_{EU15}**
Carbofuran (eco-invent 2.2)	2.4×10^{-10}	2.2×10^{-10}	2.5×10^{-11}
Carbofuran (PE)	6.1×10^{-11}	3.7×10^{-11}	2.5×10^{-11}
Ratio (eco-invent/PE)	**3.9**	**5.9**	**1.0**

Uncertainties related with pesticide impact quantification in LCA – example 3

Magnitude of cradle-to-gate uncertainties



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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 tends 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

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