Life Cycle Assessment (LCA)

What is it?
When do you use it?
What is behind it?
How do you do it?
Issues you should be aware of !

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Design for Sustainability
2023

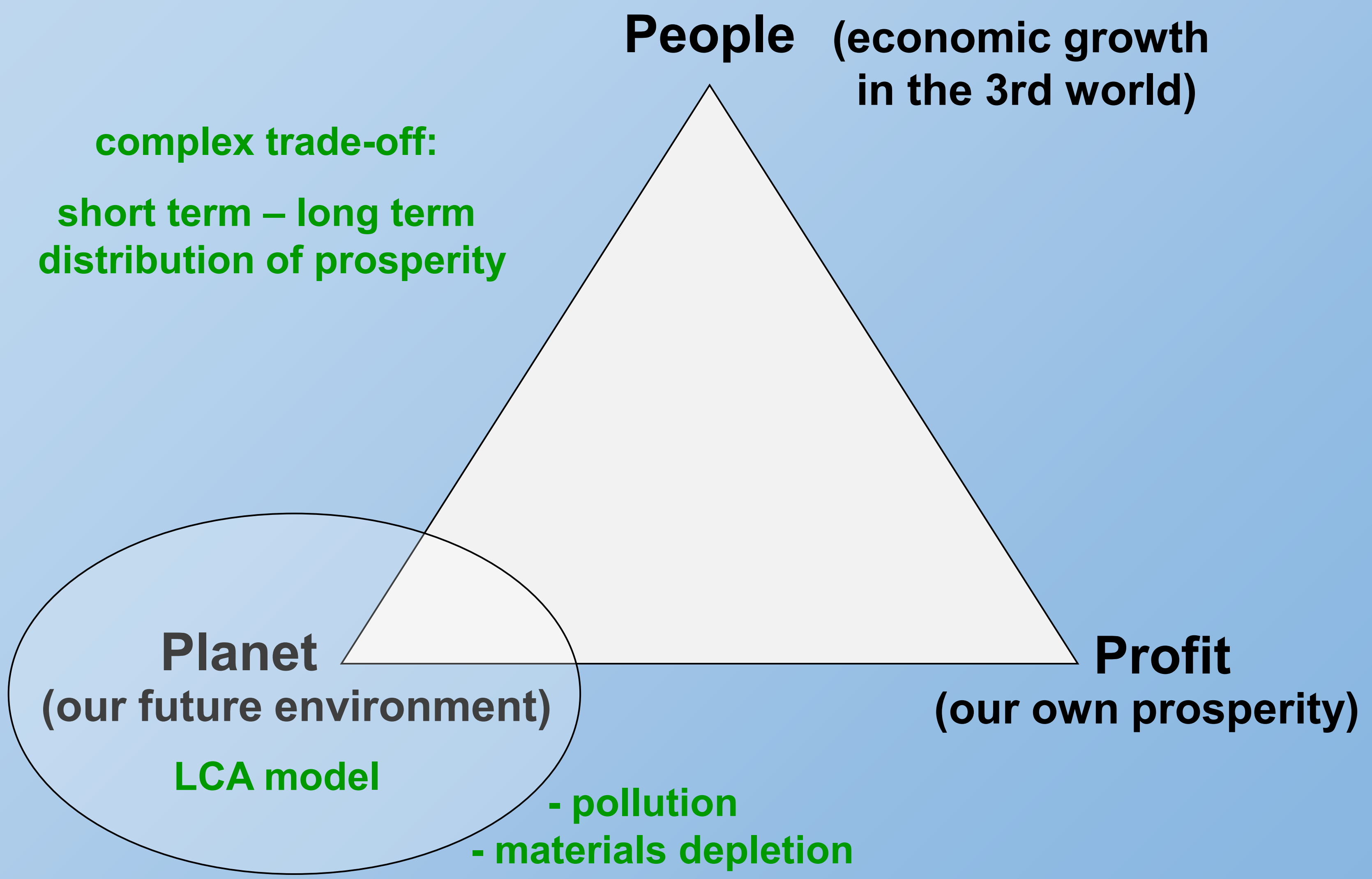
The Issues in the first lecture:

1. Why should you make an LCA?
2. The basis of the LCA: the Life Cycle Inventory (LCI)
3. Life Cycle Inventory Assessment (LCIA): “single indicator” systems

The Issues in the second lecture:

1. Case: transport packaging: an LCA in practice (the “Fast Track”)
2. Issues you should be aware of

LCA is a quantitative assessment of the P of Planet of the Triple P model of Sustainability



The Triple P model is not about “or” but about “and”

“What we need now is a new era of economic growth – growth that is forceful and at the same time socially and environmentally sustainable.”

(Brundtland, 1987)

“The delivery of competitively priced goods and services that satisfy human needs and bring ‘quality of life’,

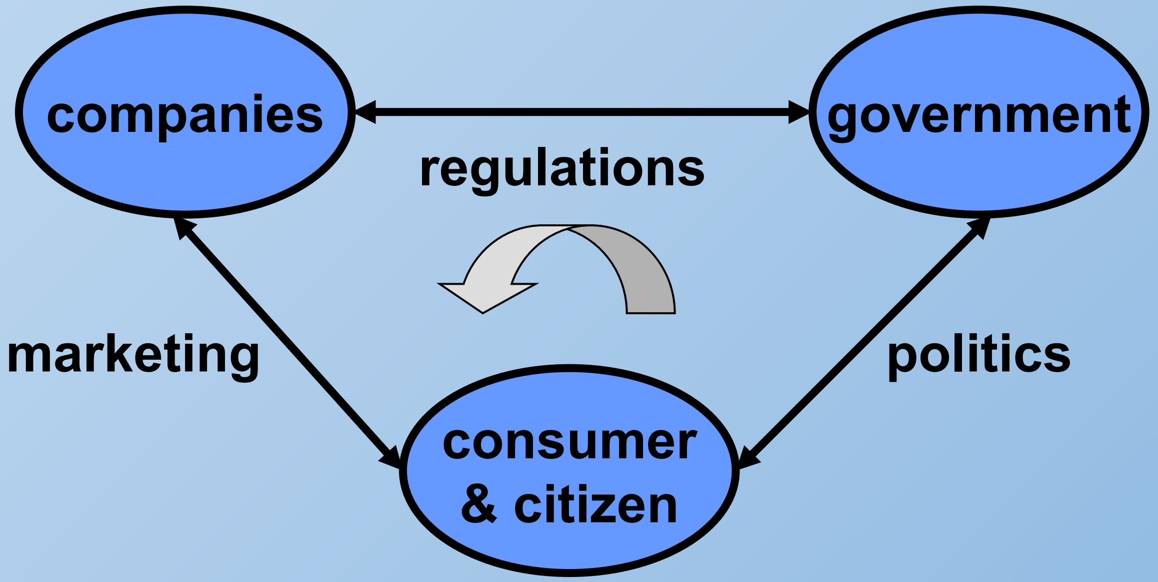
while progressively reducing ecological impacts and resource intensity, throughout the lifecycle, to a level at least in line with the earth’s estimated carrying capacity”

(WBCSD, 1995)

value
‘profit’

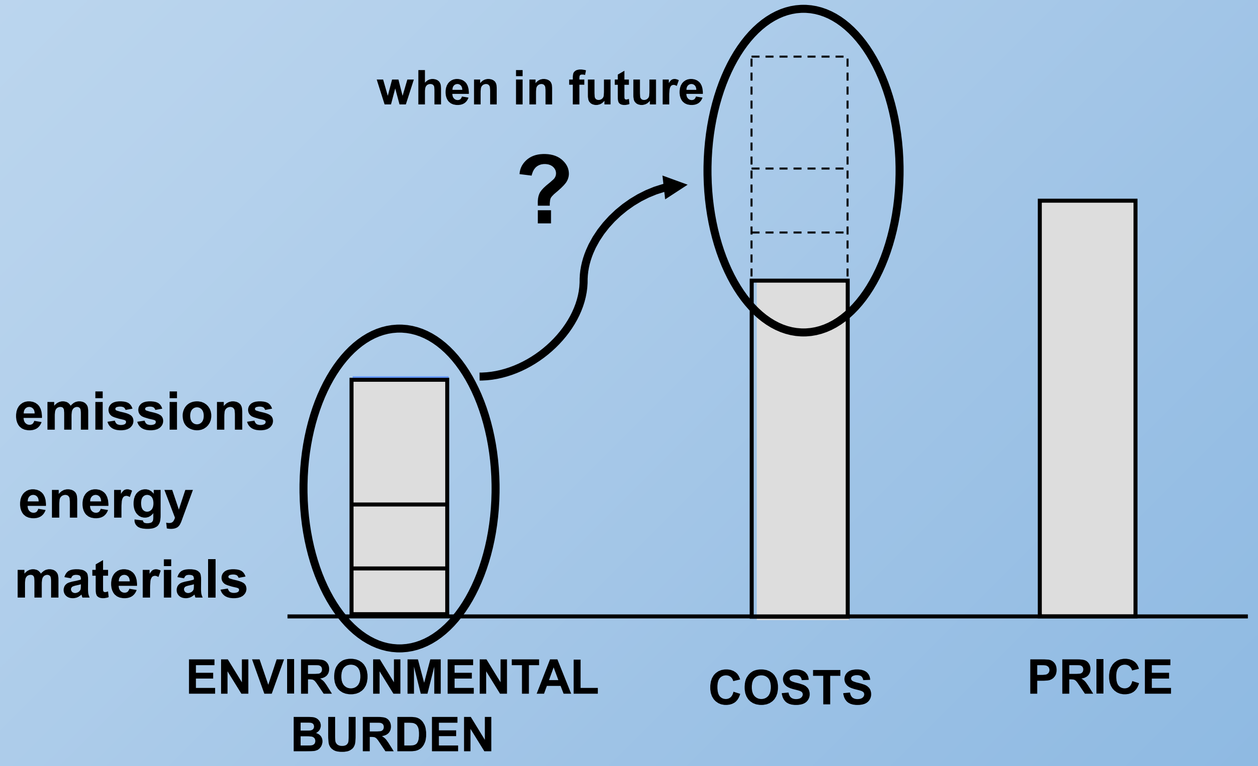
eco-costs
‘planet’

Interaction of the 3 stakeholders on the road towards sustainability



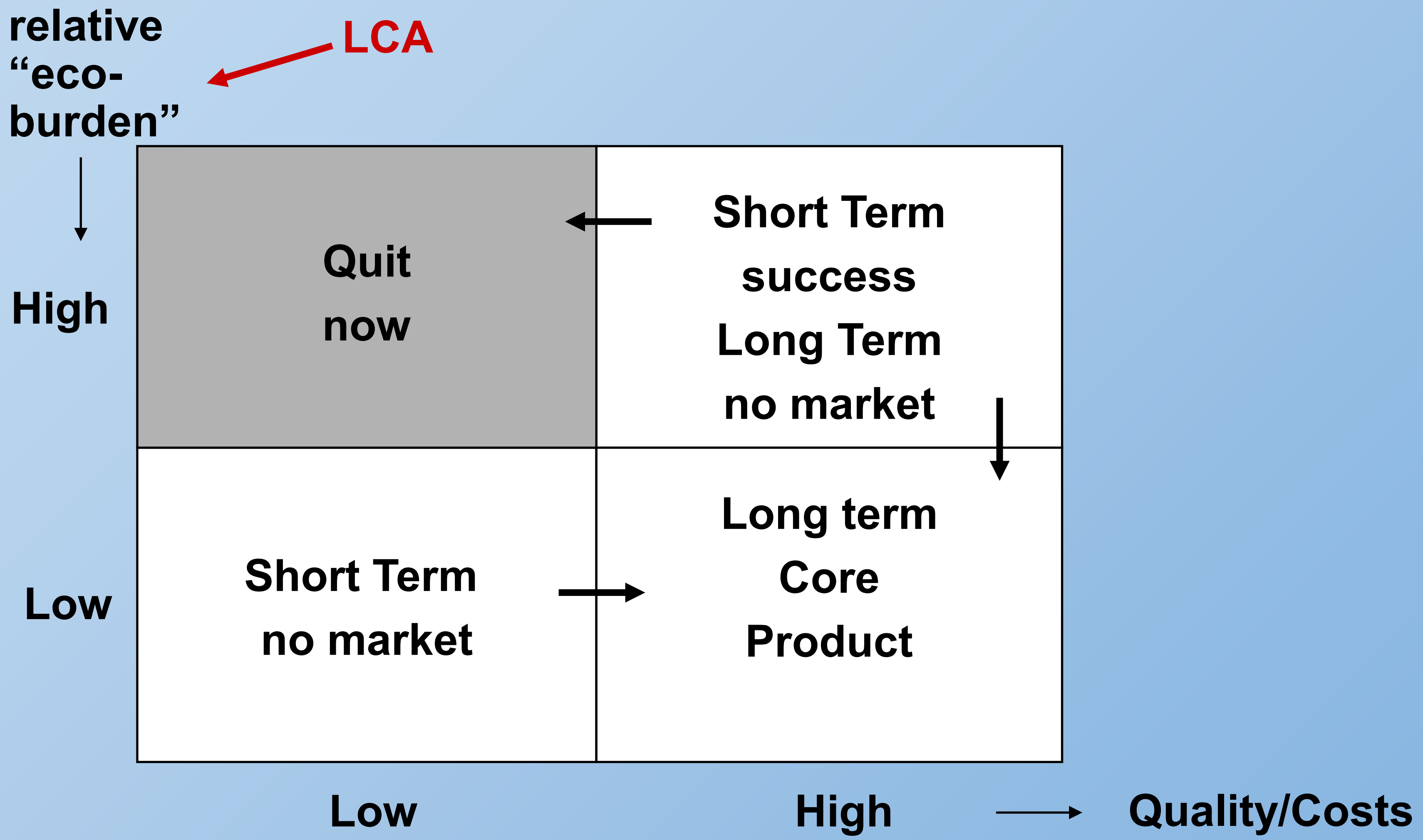
The relevance for a company:

Environmental burden will gradually become internal costs as a consequence of governmental regulations*) !
The question is not *if* but *when*.



***) - Best Available Technology**
- Tradable Emission Rights
- Eco-tax, etcetera

Product portfolio matrix for product strategy of companies



Case: transport packaging

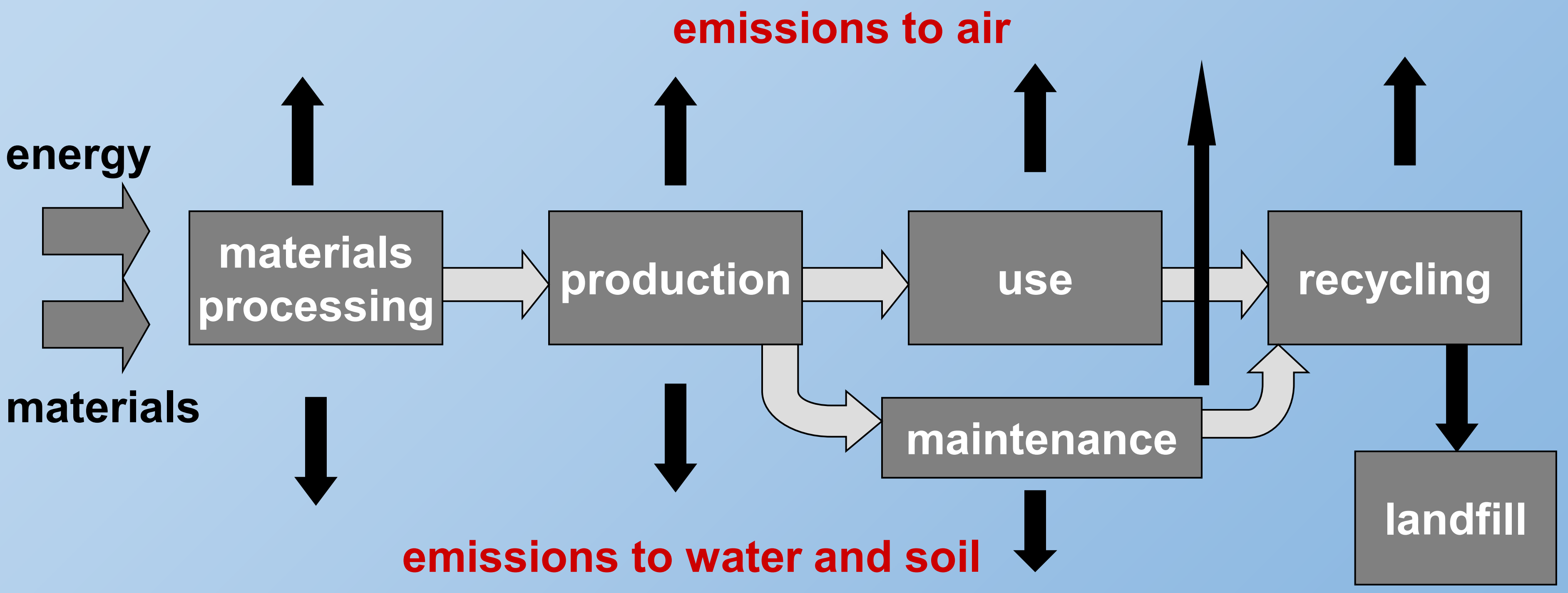
Which solution is the best choice for transport of vegetables from the Dutch greenhouse to the retail shop in Frankfurt?

1. **Corrugated box from recycled paper for fruit and vegetables**

   not reusable

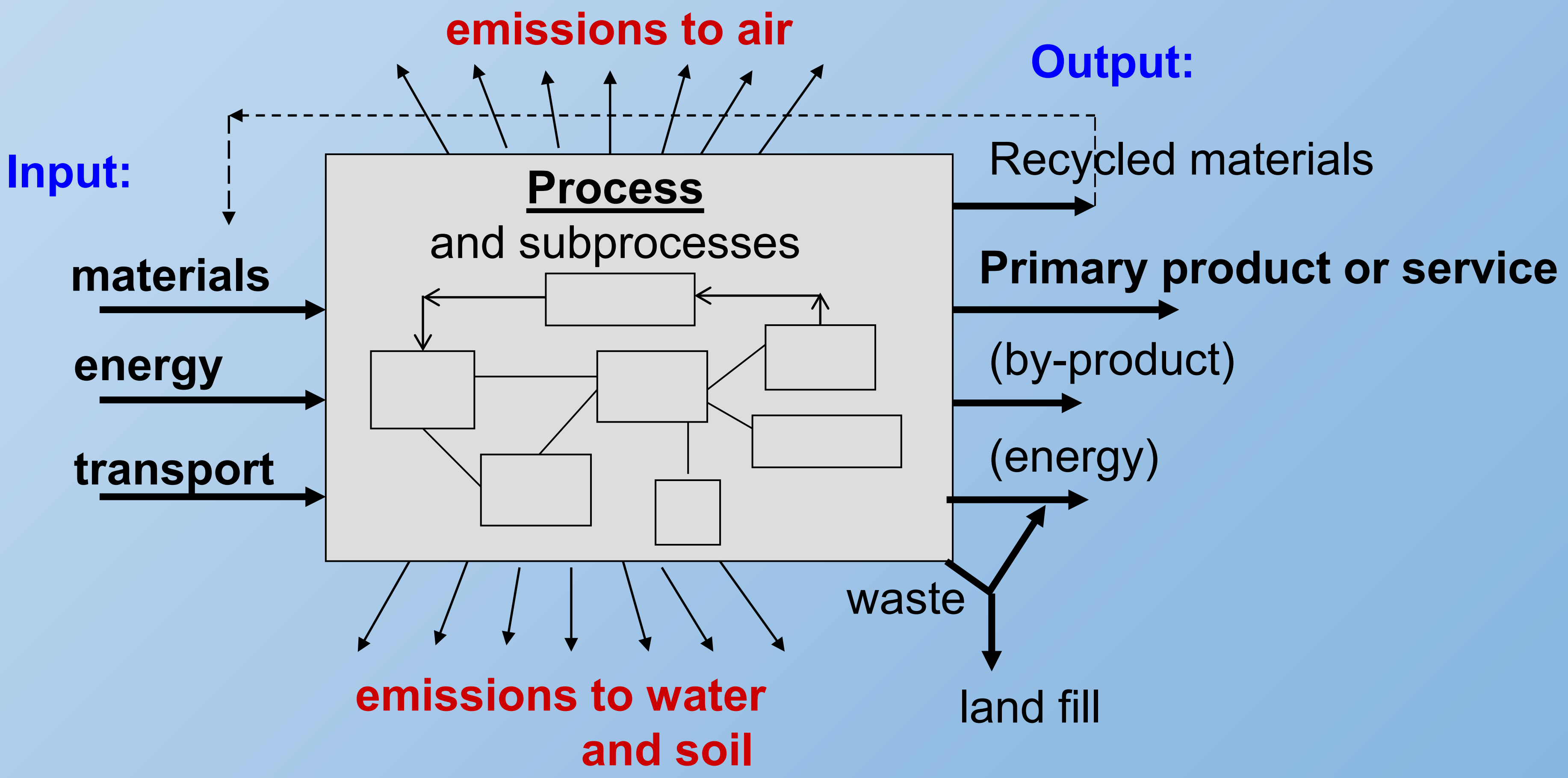
2. **Plastic re-usable crate for fruit and vegetables reusable: approx. 30 round trips**

An LCA provides data on the environmental burden “from cradle to grave”



Step 1: Life Cycle Inventory (LCI)
Step 2: Life Cycle Impact Assessment (LCIA)

The Life Cycle Inventory ;
The basic structure



There are LCIs of 18000 (!) processes in the ecoinvent v3.8 database

Compartment: All compartments
Indicator: Amount
Cut-off: 0.1 %
☐ Default units
☐ Per sub-compartment
☑ Exclude long-
☐ Skip unused
Category
☐ Per impact ca

No	Substance	Compartr	Unit	Sheep for slaughtering,
1	1-Butanol	Air	µg	5.57
2	1-Butanol	Water	µg	57.9
3	1-Pentanol	Air	µg	2.33
4	1-Pentanol	Water	µg	5.6
5	1-Pentene	Air	µg	1.77
6	1-Pentene	Water	µg	4.23
7	1-Propanol	Air	µg	27.1
8	1-Propanol	Water	µg	10.7
9	1,3-Dioxolan-2-one	Water	µg	14.8
10	1,4-Butanediol	Air	µg	7.25
11	1,4-Butanediol	Water	µg	16.7
12	2-Aminopropanol	Air	µg	2.43
13	2-Aminopropanol	Water	µg	5.85
14	2-Butene, 2-methyl-	Air	pg	361
15	2-Butene, 2-methyl-	Water	pg	866
16	2-Methyl-1-propanol	Air	µg	7.26
17	2-Methyl-1-propanol	Water	µg	17.4
18	2-Methyl-4-chlorophenoxyacetic acid	Air	pg	5.63E-5
19	2-Methyl-4-chlorophenoxyacetic acid	Water	pg	0.000125
20	2-Methyl-4-chlorophenoxyacetic acid	Soil	ng	1.26
21	2-Nitrobenzoic acid	Air	µg	5.1
22	2-Propanol	Air	µg	451
23	2-Propanol	Water	µg	299

Comparing 1 kg 'Sheep for slaughtering, live weight {US}| sheep production, for meat | Cut-off, U'; Method:

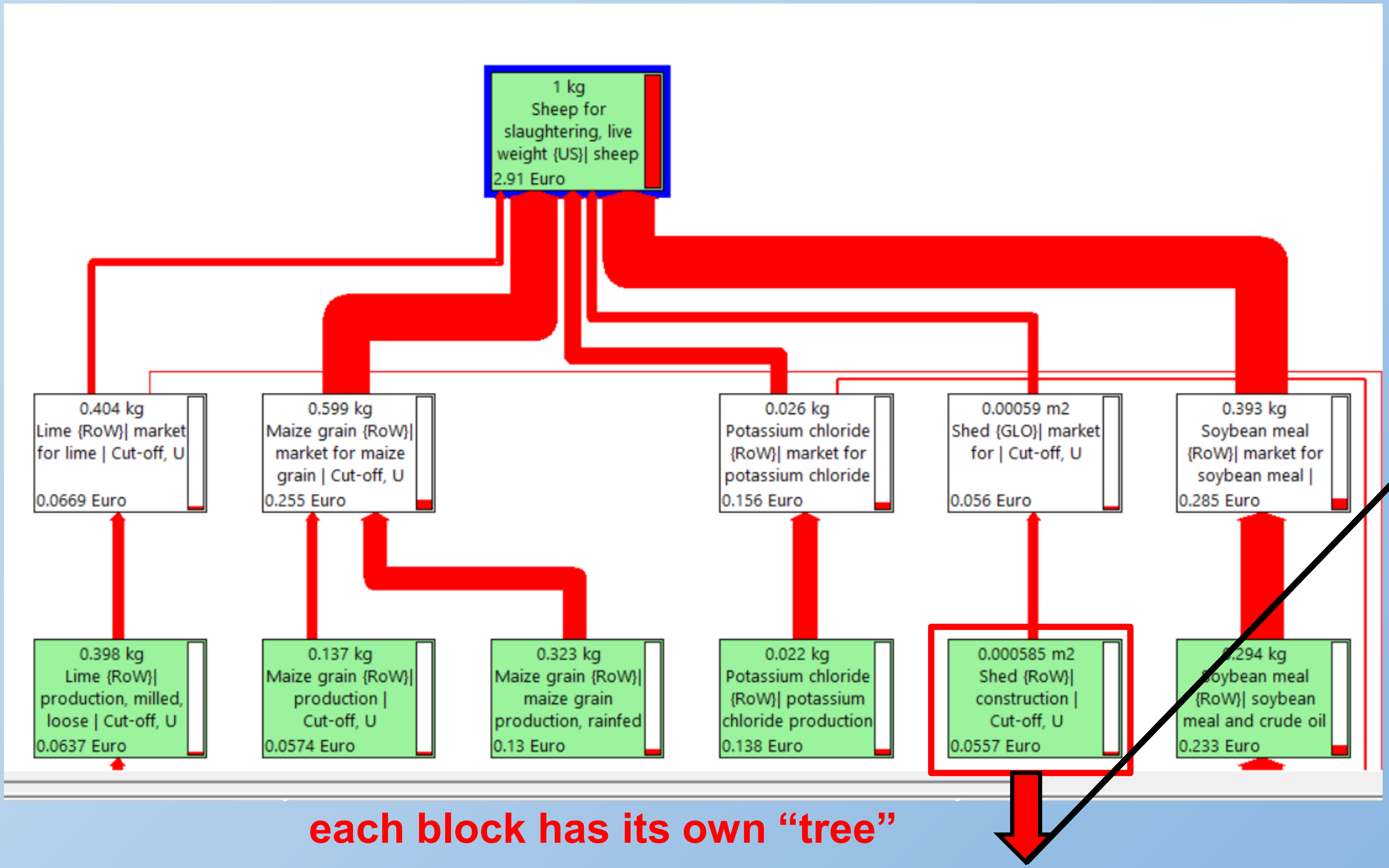
Example:

Sheep for slaughtering at farm gate

emissions to air and water
1832 (!) lines

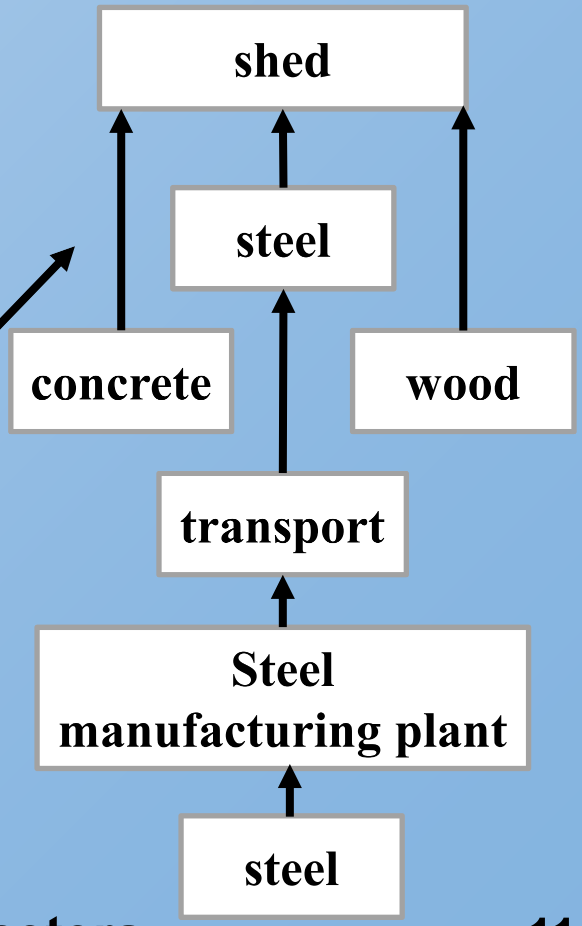
There are LCIs of 18000 (!) processes in the ecoinvent v3.8 database

Example: Sheep for slaughtering at farm gate (the first level only)



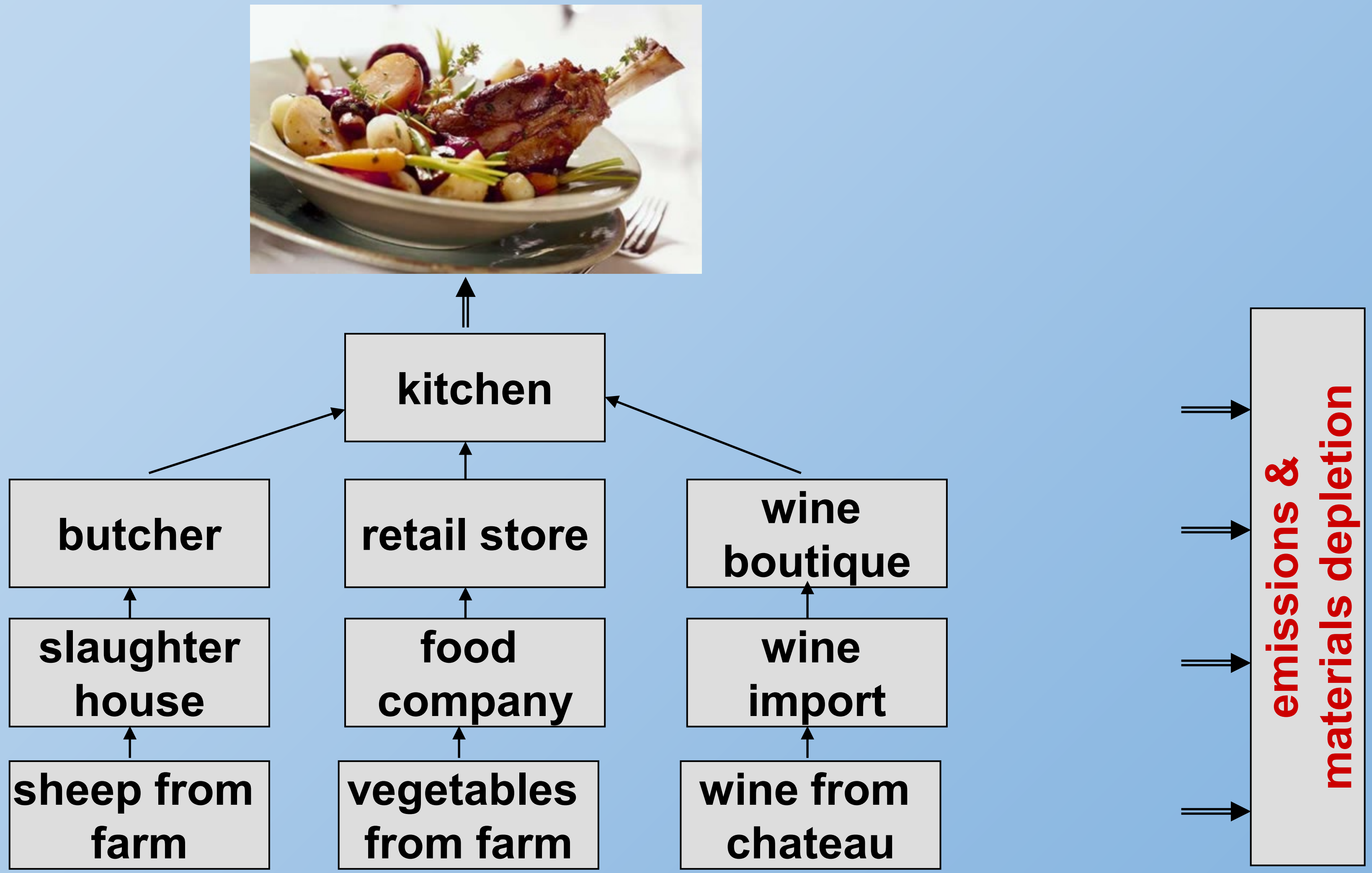
each block has its own "tree"

You can dig deeper and deeper, for instance:

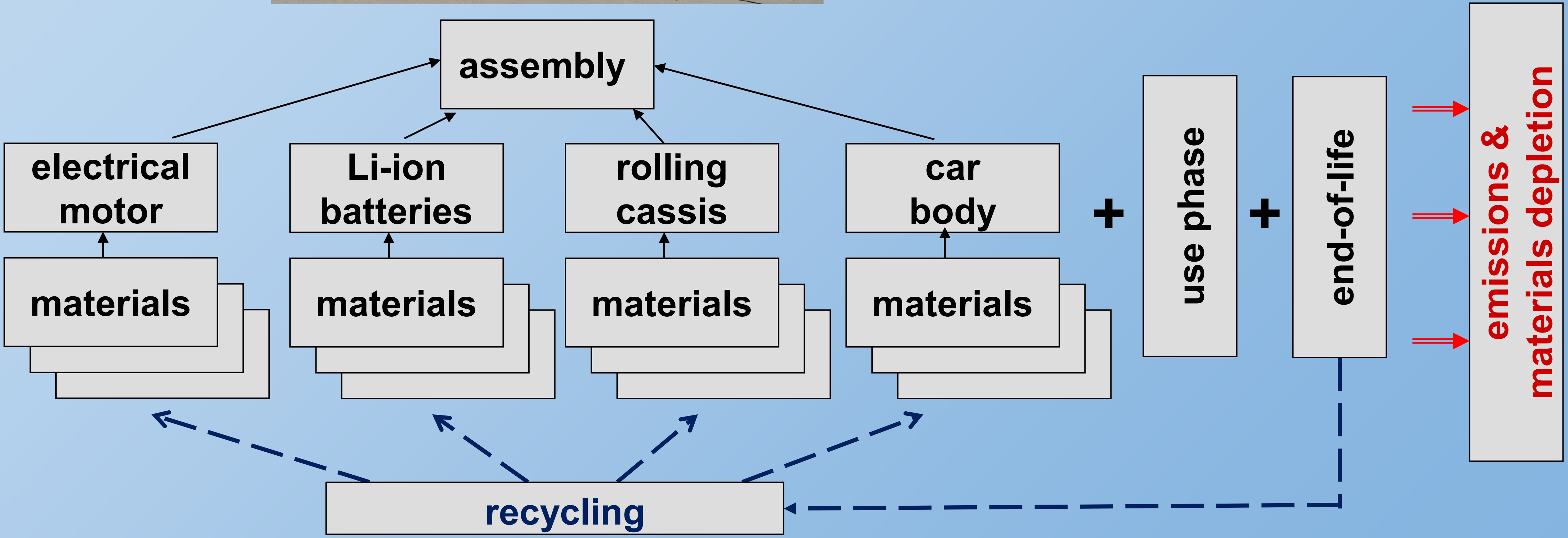


etcetera

The “tree” of a meal



The “tree” of a Volvo C40 Recharge



The next step: Life Cycle Impact Assessment (LCIA) = creating a "single indicator"

3 types of single indicator systems:

- based on 1 "single issue"	the Carbon Footprint (CO_2)
- based on damage	the Recipe 2016 / Environmental Footprint
- based on prevention costs	the Eco-costs 2023

Which choice?

I recommend the eco-costs:

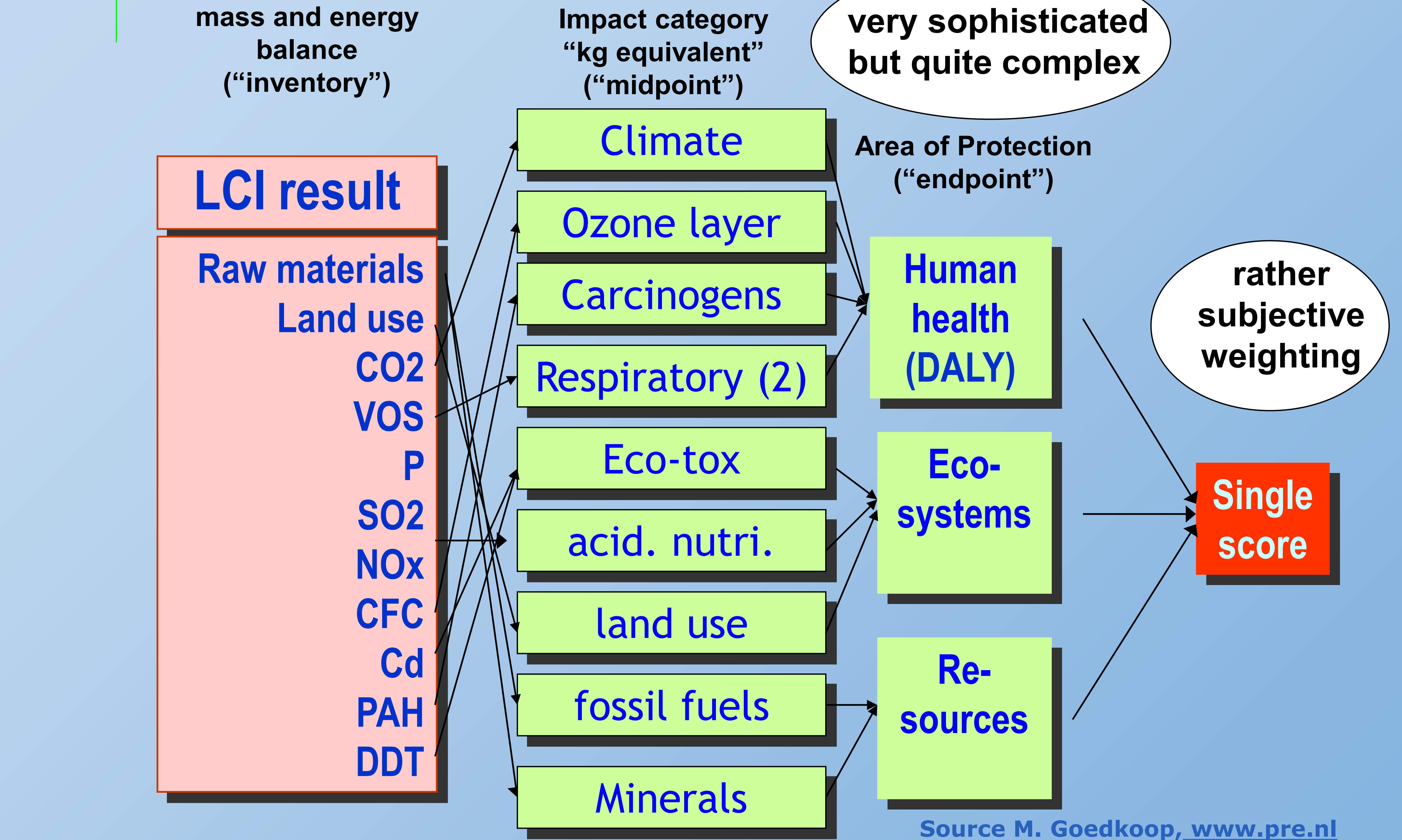
1. It includes toxicity (e.g. NO_2 and NH_3, fine dust), materials scarcity, plastic soup, water, biodiversity

2. It is a straightforward calculation system, without weighting

3. It is related to BATNEC
   (best available technologies not entailing excessive costs)
   It is a proxy for future levels of tradable emission rights or taxes

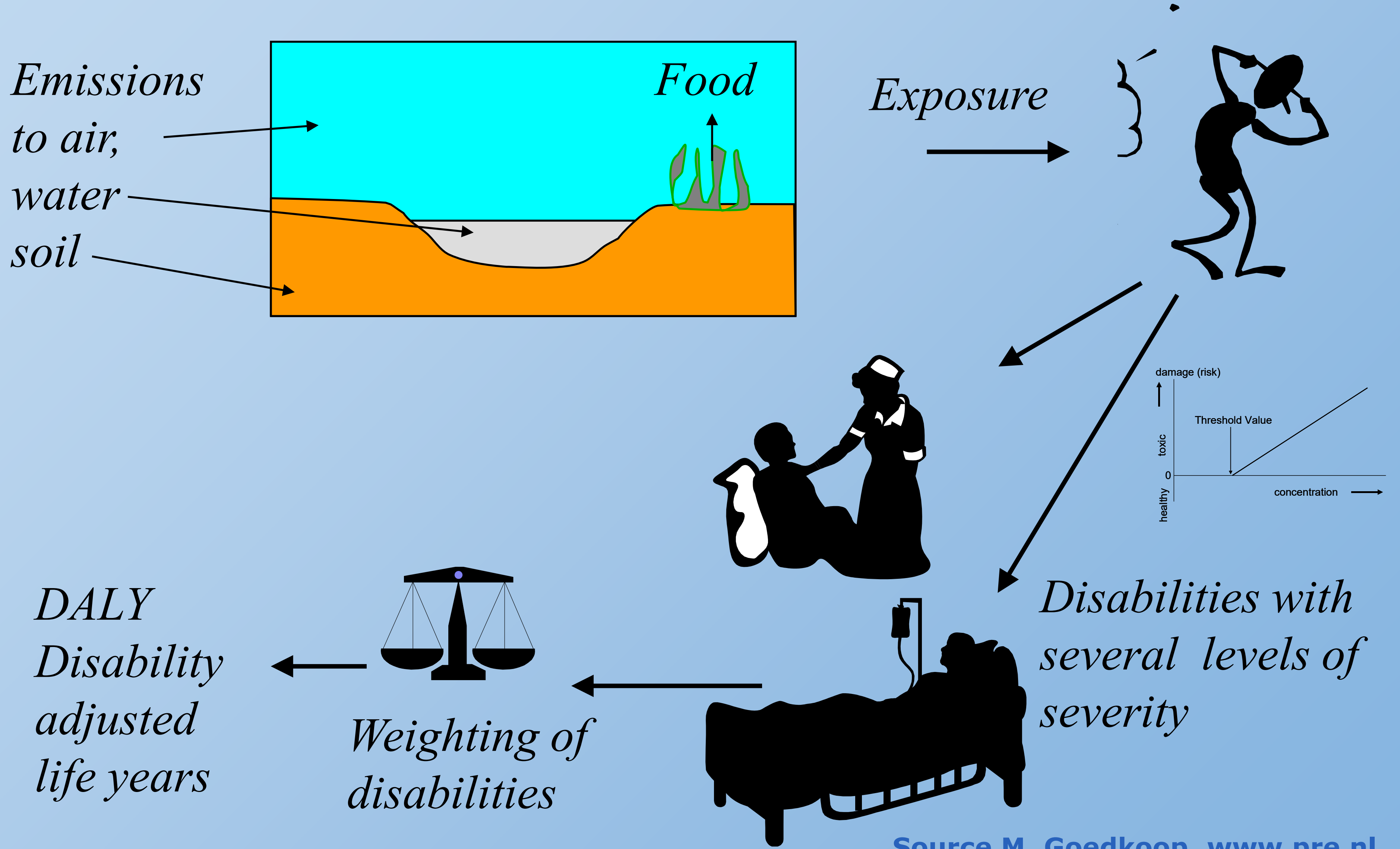
4. <u>It is suitable for Cradle to Cradle calculations,</u>
   <u>taking into account recycling ("closing the loop")</u>
   (the Carbon Footprint is not suitable for C2C calculations)

The original idea: a damage based system



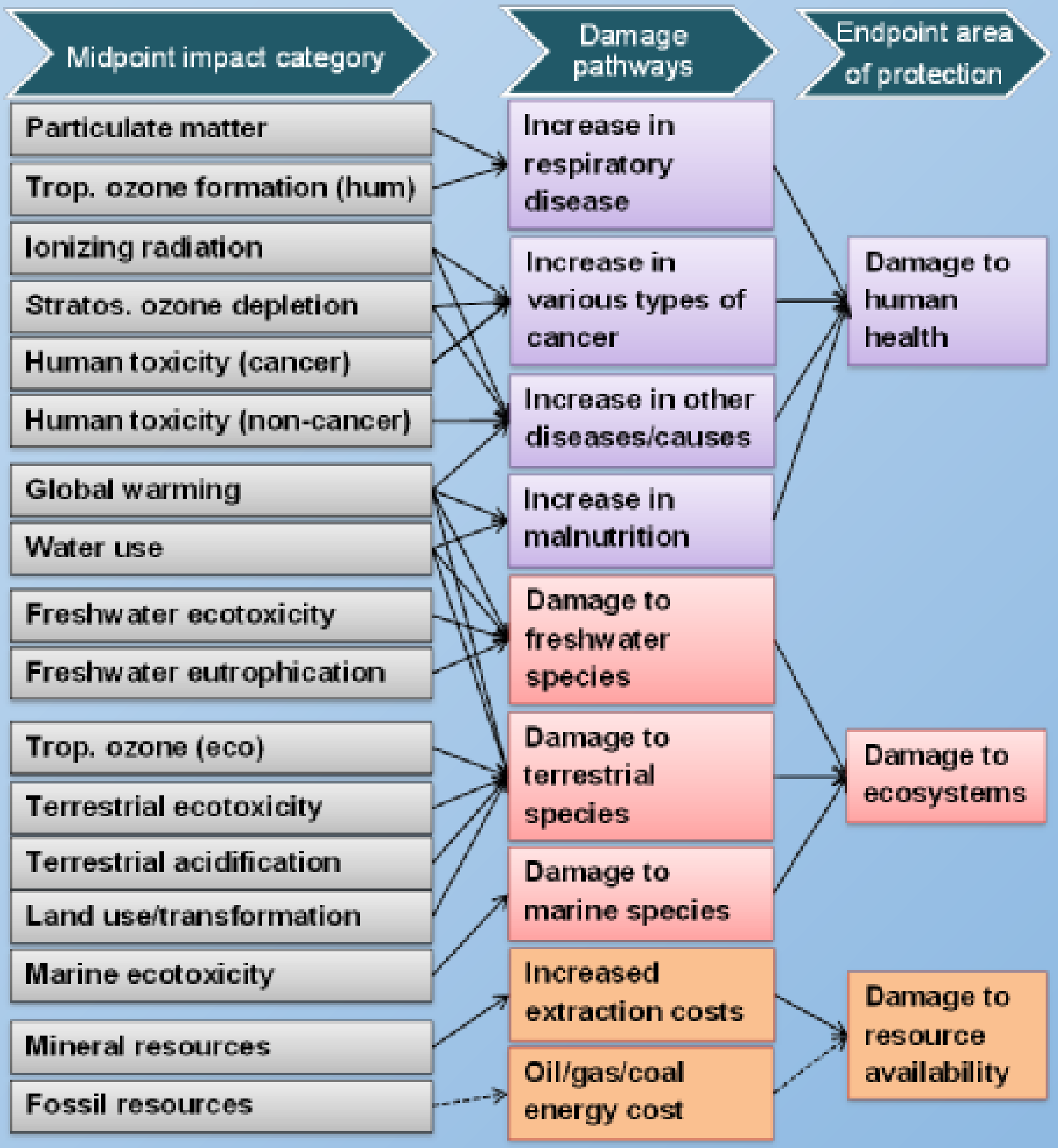
Source M. Goedkoop, www.pre.nl

From emissions to human health, a complex calculation



Source M. Goedkoop, www.pre.nl

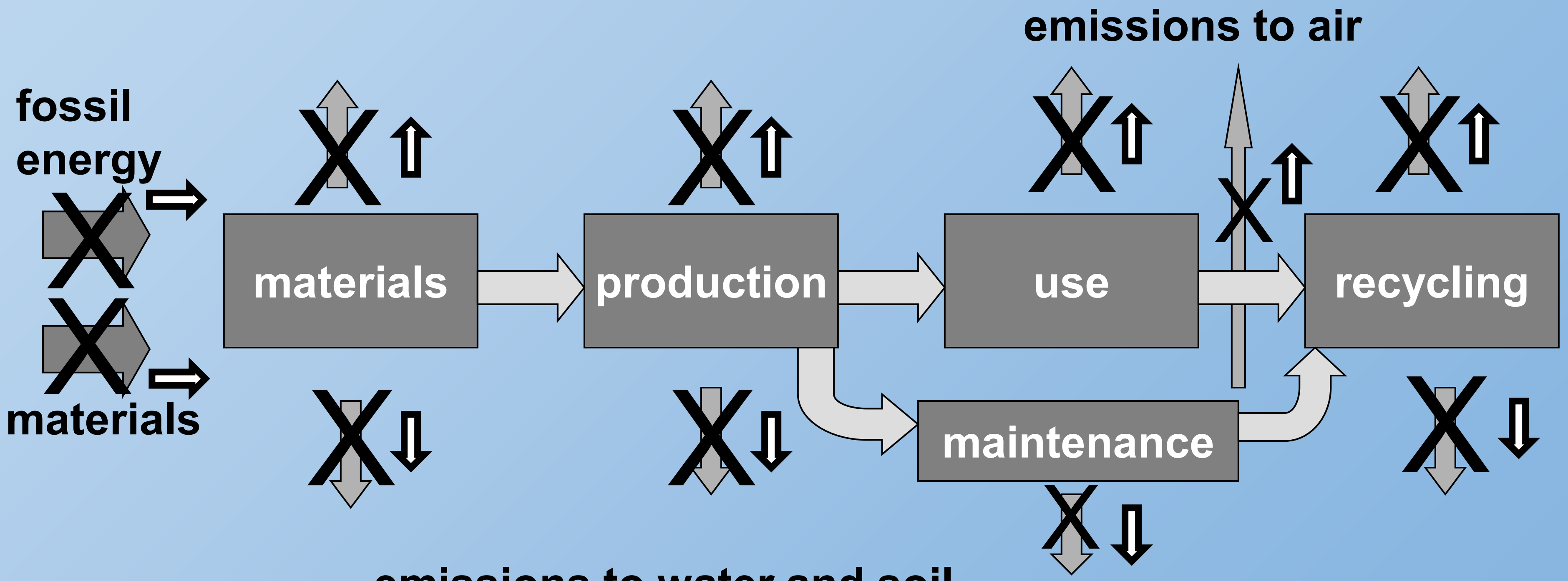
Recipe 2016, the best damage based system:
even more complex, but better? (and still subjective weighting)



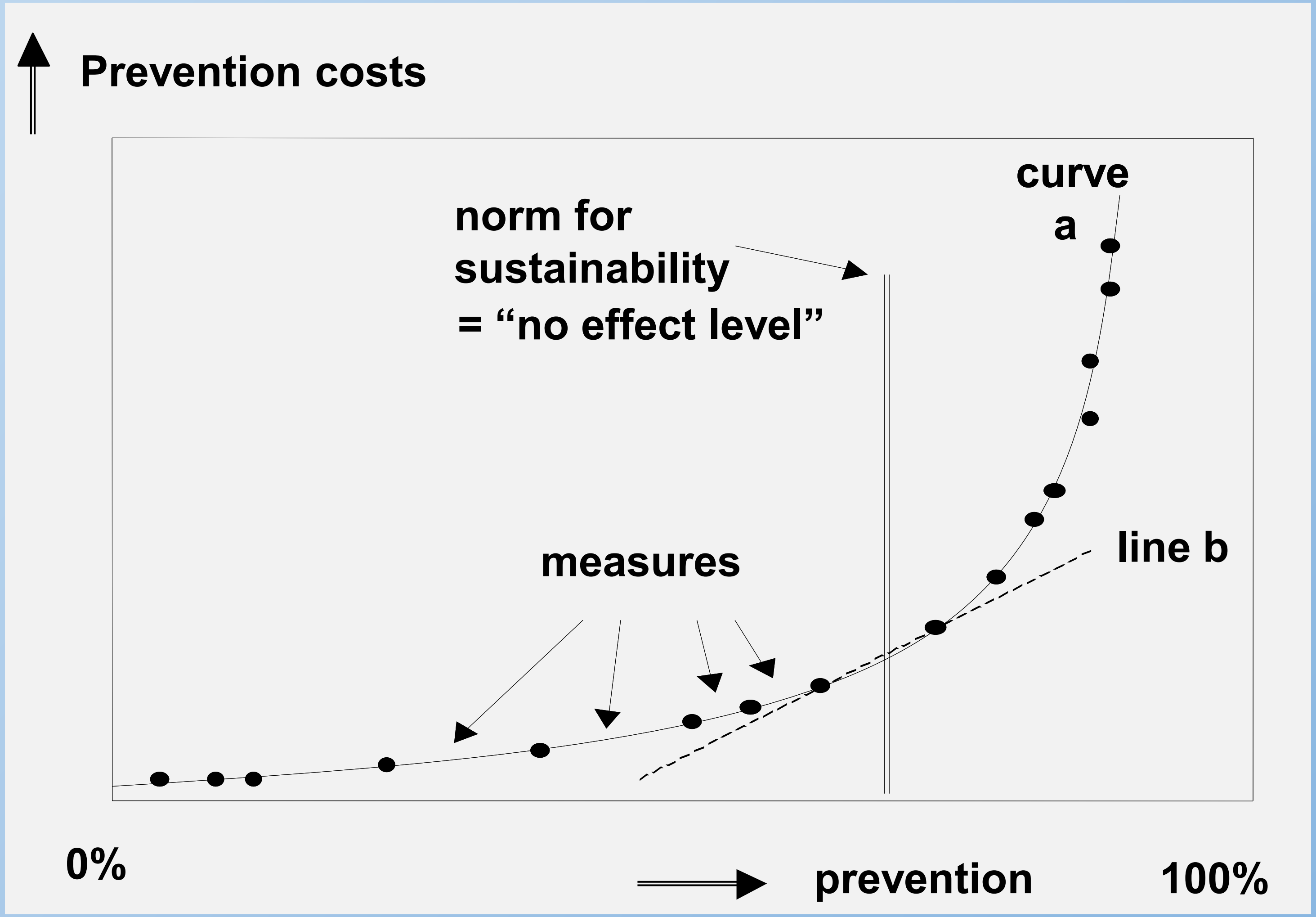
Source M. Goedkoop, www.pre.nl

A total different concept: the Eco-costs 2022 based on the 'marginal prevention costs' (external costs, or "hidden obligations")

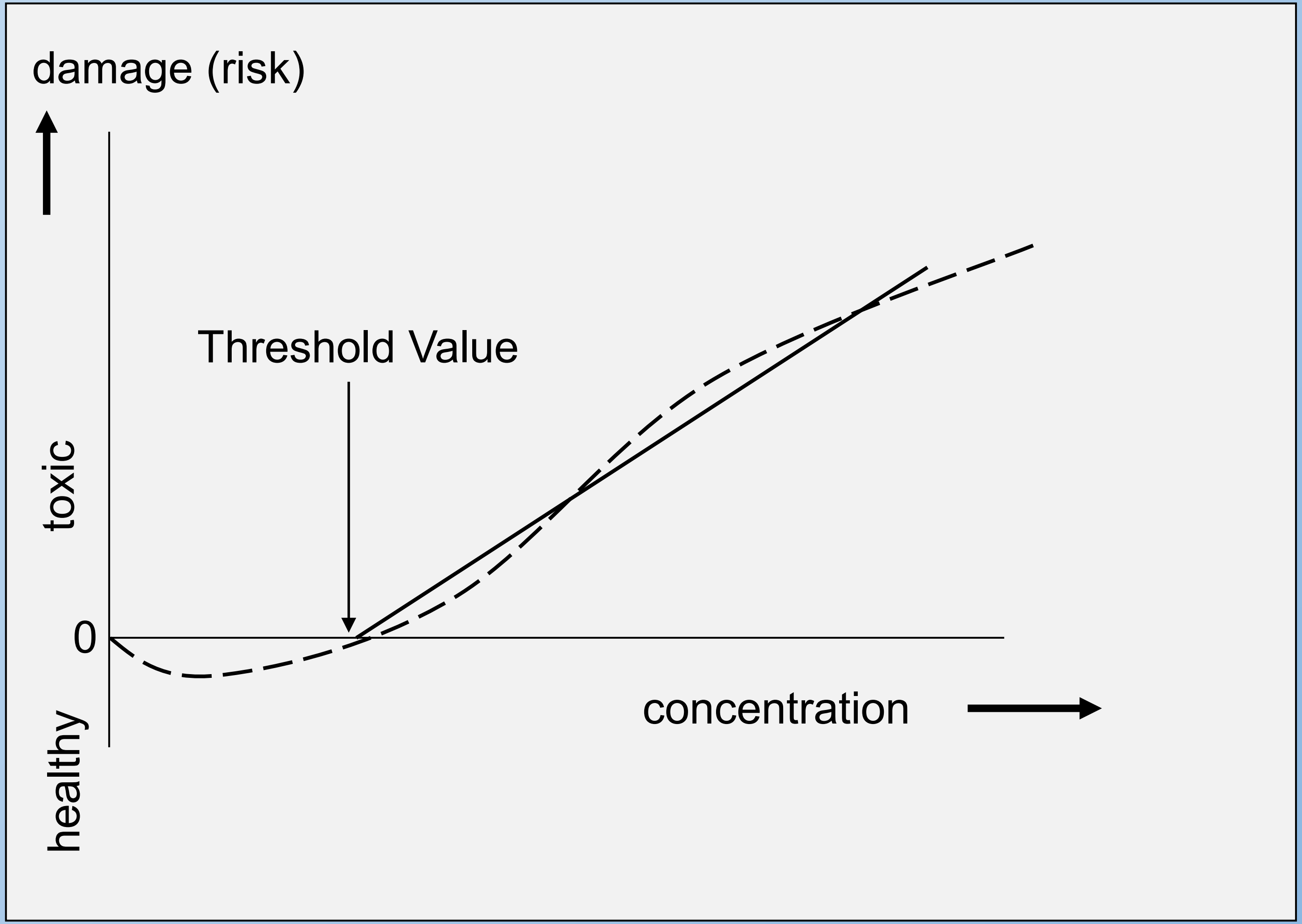
"the eco-costs are the costs of prevention measures, which are required to reduce the current emissions, to a sustainable level"



Eco-costs are based on marginal prevention costs at the "no-effect level"
(the costs in euro/kg of technical measures)



Note that many toxic materials have a threshold,
and the damage is not proportional to the concentration!



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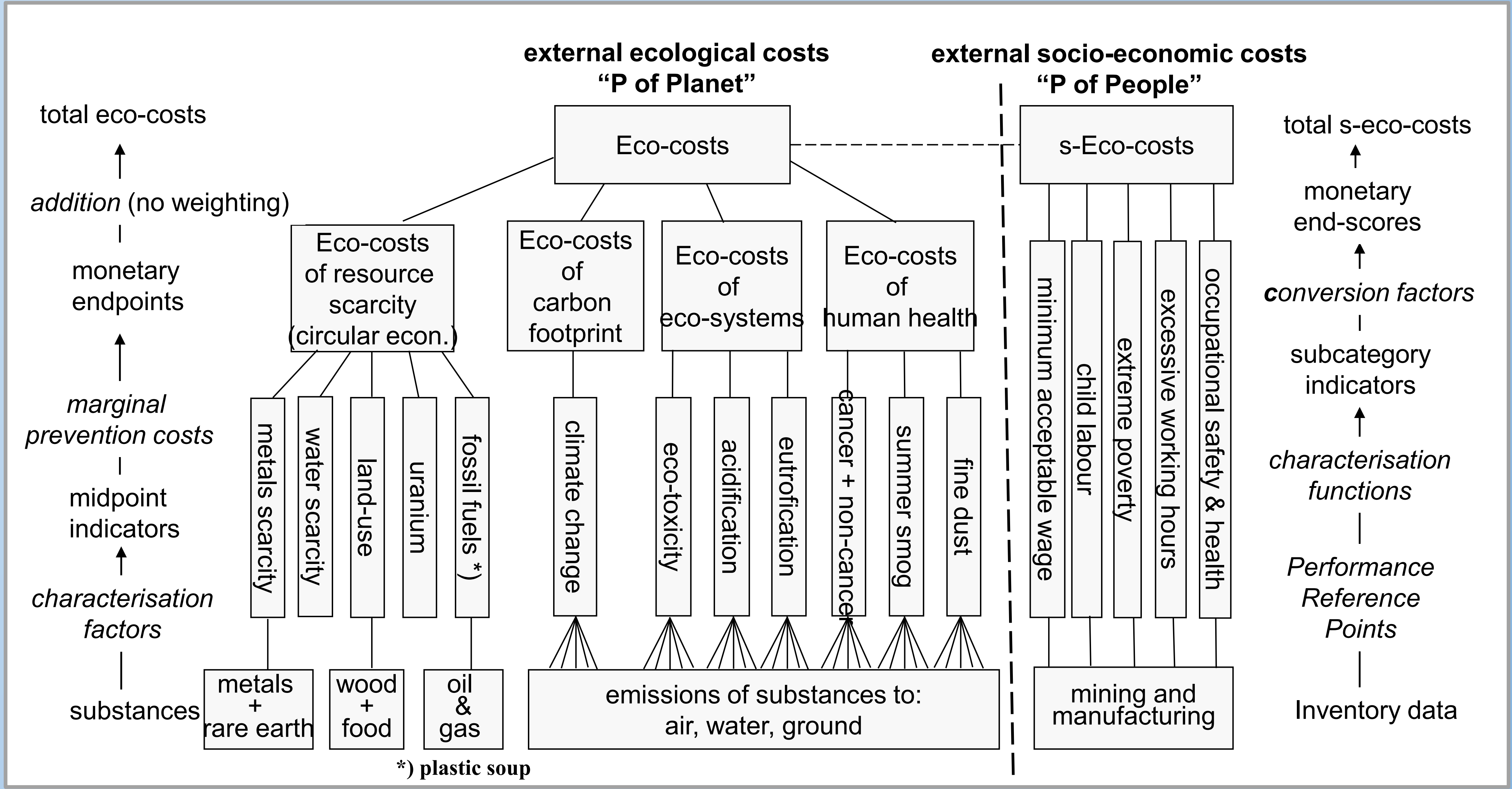
The main structure of eco-costs (as a “single indicator” of LCA)



for details see www.ecocostsvalue.com

The Life Cycle Inventory Analysis:
Each emission has its own multiplier

kg CO2 equ / kg

Compar	Subcon	Substance	CAS number	Factor	Unit
Air		Butane, perfluorocyclo-, PFC-318	000115-25-3	10600	kg CO2 eq / kg
Air		Butanol, 2,2,3,3,4,4,4-heptafluoro-	000375-01-9	41	kg CO2 eq / kg
Air		Butanol, 2,2,3,3,4,4,4-heptafluoro-1-	000375-01-9	20	kg CO2 eq / kg
Air		Butanol, 2,2,3,4,4,4-hexafluoro-1-	000382-31-0	21	kg CO2 eq / kg
Air		Carbon dioxide	000124-38-9	1	kg CO2 eq / kg
Air		Carbon dioxide, biogenic	000124-38-9	0	kg CO2 eq / kg
Air		Carbon dioxide, fossil	000124-38-9	1	kg CO2 eq / kg
Raw		Carbon dioxide, in air	000124-38-9	0	kg CO2 eq / kg
Air		Carbon dioxide, land transformation	000124-38-9	1	kg CO2 eq / kg
Soil		Carbon dioxide, to soil or biomass stock	000124-38-9	-1	kg CO2 eq / kg
Air		Carbon monoxide	000630-08-0	1.57	kg CO2 eq / kg
Air		Carbon monoxide, biogenic	000630-08-0	0	kg CO2 eq / kg
Air		Carbon monoxide, fossil	000630-08-0	1.57	kg CO2 eq / kg
Air		Carbon monoxide, land transformation	000630-08-0	1.57	kg CO2 eq / kg
Air		Chloroform	000067-66-3	20	kg CO2 eq / kg
Air		Cis-perfluorodecalin			
Air		Decane, 1,1,...,15,15-eicosafluoro-[illegible]	[illegible]	[illegible]	[illegible]
Air		Decane, 1,1,3,3,4,4,6,6,7,7,9,9,10,10,12,12-hexadecafluoro-	173350-37-3	5250	kg CO2 eq / kg
Air		Decane, 1,1,3,3,5,5,7,7,8,8,10,10-dodecafluoro-2,4,6,9-tetra	249932-26-1	4630	kg CO2 eq / kg
Air		Decane, 1,1,3,3,5,5,7,7,9,9-decafluoro-2,4,6,8-tetraoxanona	188690-77-9	8580	kg CO2 eq / kg
Air		Dinitrogen monoxide	010024-97-2	298	kg CO2 eq / kg
Air		**Methane** in “IPCC2013 GWP 100” 24 -> 30 -> 36 in eco-costs:		**30**	kg CO2 eq / kg

example greenhouse gasses in Simapro

Eco-costs 2023:

1 kg CO2 equ = 0,123 €

For all midpoints: Eco-costs of more than 58.000 substance types

From classical LCA towards "Fast Track" LCA:
= from big database manipulations towards "lookup tables"

Classical LCA →	Required transformation →	Fast Track LCA
Complex database manipulations (in Simapro, OpenLCA)	Simplification, but **the same accuracy**. User-friendly. Compliant with the same LCA rules	Look-up tables in excel + simple excel calculations For design, engineering and architecture.
58.000 substances	Compressing (by Simapro)	12 midpoints (eco-costs)
18.000 LCIs in Ecoinvent	Eliminating: - double counting (factor 2) - unnecessary subs (factor 3) - less agri and waste (factor 2)	1600 LCIs in Idemat (Idemat has even more materials and practical end-of-life data)

"Fast track": don't bother about LCI and LCIA but take directly the output data of Simapro calculations

materials

Eco-costs

Sustainability Impact Metrics | Customizer | 9 | 6 | Nieuw | Bewerk Pagina (Geavanceerde l

Sustainability Impact Metrics
A spin-off of the Delft University of Technology

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Excel files: Idemat and Ecoinvent, a

There are three different 'background' datasets ('scope 2 and 3'):

- The **scope 3** Idemat dataset, with some **scope 2** data for heat and electricity, is based on a set of carefully selected LCIs from peer reviewed literature and scientific databases of universities. The latest version is
  Idemat 2023.xlsx
  (the version Idemat 2022RevA.xlsx is still available).
  The Idemat datasets contain Simapro output on **eco-costs, carbon footprint, ReCiPe points, CED and EF.**
- The special **scope 2** dataset for electricity is **Idemat 2021 Global Electricity** . It includes worldwide electricity data of 218 countries plus the 26 electricity regions in the US, 44 provinces in India, 13 provinces of Canada and 31 provinces in China
  and accurate
  in LCA
  Note 2: the original calculation of the Idemat 2021 Global Electricity applies data from 2019. For 2020 and 2021 data were not stable because of covid-19. For 2022 data are not stable because of the war in the Ukraine. We will wait for 2023 data to make new calculations.
- the **Scope 2 and 3** Ecoinvent dataset with eco-costs (EI V3-7 with eco-costs.xlsx) *is available behind password*

https://www.ecocostsvalue.com/data/

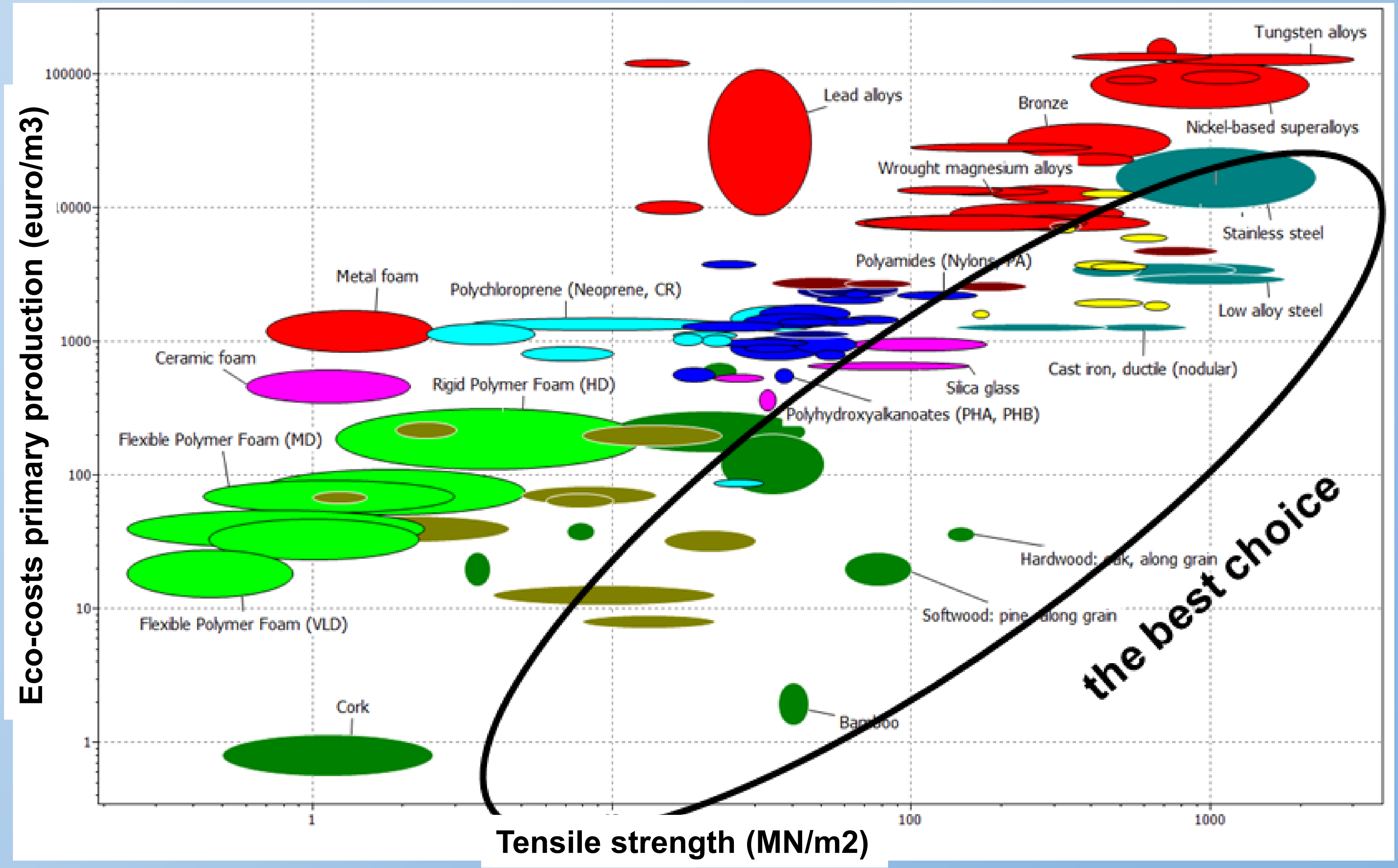
Process	Total eco-costs euro
Idemat2023 Silicone rubber (PDMS)	1.77
rials, plastics, Thermoplasts	
Idemat2023 ABS (Acrylonitrile butadiene styrene)	1.31
Idemat2023 ABS 30% glass fibre	1.00
Idemat2023 Ionomer	3.15
Idemat2023 PA 6 (Nylon 6, P	1.64
Idemat2023 PA 6 GF30	1.23
Idemat2023 PA 66 (Nylon 66	1.61
Idemat2023 PA 66 GF30	1.20
Idemat2023 PB-1 (Polybutyle	1.13
Idemat2023 PC (Polycarbona	1.27
Idemat2023 PC 30% glass fib	0.97
Idemat2023 PE (HDPE, High	1.16
Idemat2023 PE (LDPE, Low	1.17
Idemat2023 PE (LLDPE, Line	1.15
Idemat2023 PE (Polyethylene	1.25
Idemat2023 PEEK (Polyetheretherketone), obsolete, moved to Special plastics	0.00
Idemat2023 PET 30% glass fibre	0.80
Idemat2023 PET amorphous	1.01
Idemat2023 PET bottle grade	1.03
Idemat2023 PMMA (Polymethyl methacrylate)	
Idemat2023 POM (Polyoxymethyleen, polyacetaal)	
Idemat2023 PP (Polypropylene)	
Idemat2023 PP GF30	
Idemat2023 PS (EPS, expandable polystyrene)	
Idemat2023 PS (GPPS, general purpose polystyren	
Idemat2023 PS (HIPS, high impact polysyrene)	
Idemat2023 PTFE (Teflon, Polytetrafluoroethylene)	
Idemat2023 PTT (Polyltrimethylene terephthalate)	0.93
Idemat2023 PVA (wood glue)	1.32
Idemat2023 PVC (Polyvinylchloride emulsion polymerised)	0.81

PA 66 GF30
PB-1 (Polybutylene)
PC (Polycarbonate)
PC 30% glass fibre
PE (HDPE, High density Polyethylene)
PE (LDPE, Low density Polyethylene)
PE (LLDPE, Linear low density Polyethy

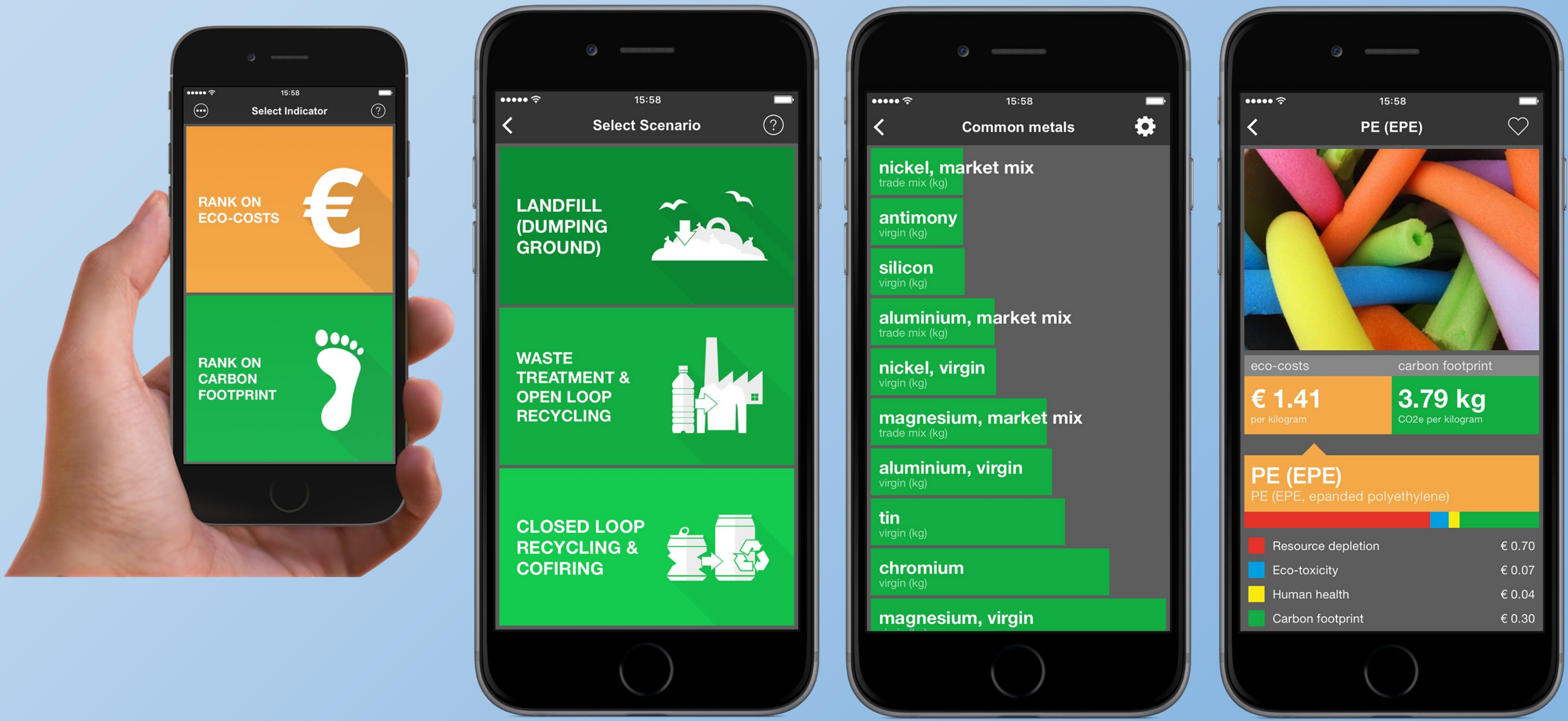
Carbon Footprint
Cum Energy Demand
ReCiPe
Environmental Footprint

Direct use of the Idemat data for materials selection

(Ashby charts are available at www.ecocostsvalue.com/data/ashby-charts/)

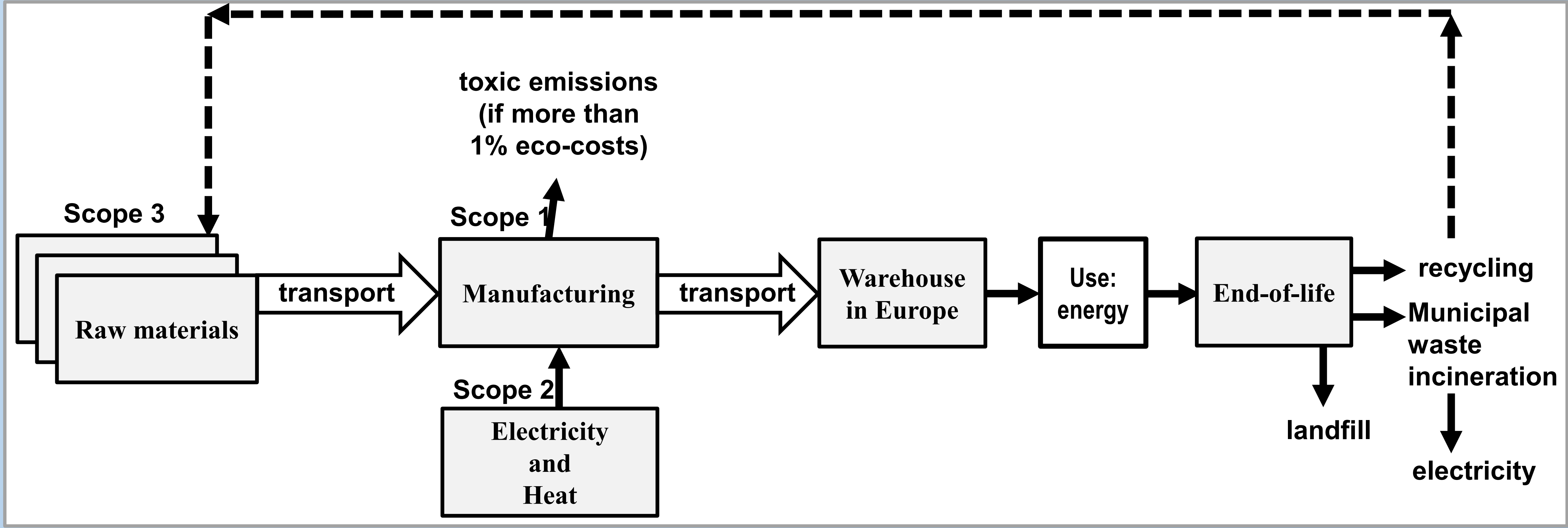


Direct use of the IdematLightLCA app for materials selection
(to be downloaded from the App store or the Google Play store)



Concluding

Our system:



Our data: the IDEMAT tables with eco-costs

Case: transport packaging

“which solution is the best choice for transport of vegetables from the Dutch greenhouse to the retail shop in Frankfurt?”

Corrugated box from recycled paper
for fruit and vegetables
not reusable

Plastic re-usable crate
for fruit and vegetables
reusable: approx. 30 round trips

The case: LCA on Transport Packaging

the box and the crate, what is the functional unit?

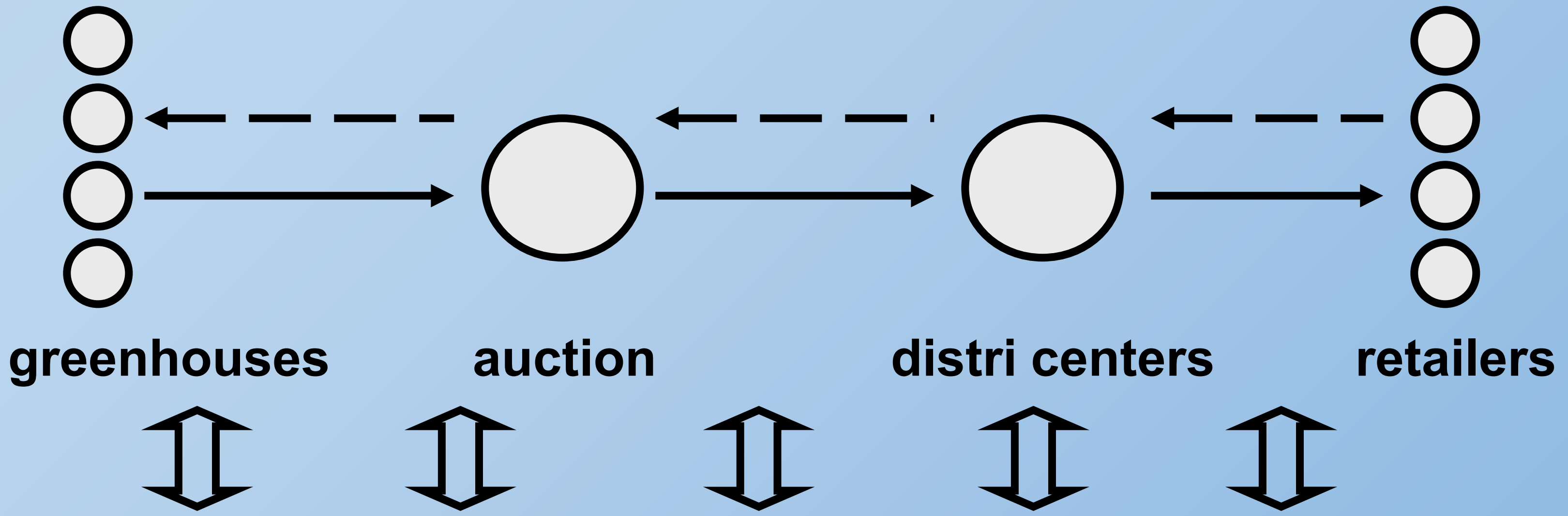
(green numbers are from the database)

	Corrugated BOX		Plastic CRATE	
Size (L,W,H) (m)	0,6 x 0,4 x 0,24		0,6 x 0,4 x 0,24	
Volume (litres)	53,40		43,92	
Weight (kg)	1,086		1,95	
Eco-costs rec. paper	0,098	Ecocosts PP		1,133
Eco-costs box making	0,022	Ecocosts moulding		0,021
	--------(+			--------(+
Eco-costs (€/kg)	0,120		1,154	
Eco-costs (€/unit)	0,13		2.250	
Nr of trips	1		30	
Eco-costs (€/trip)	0,130		0,075	
Eco-costs (€/litre)	0,0024		0,0017	

….however, the functional unit is not packaging volume, but transport….

The case: LCA on Transport Packaging

transport of vegetables from greenhouse to retailer



Partly usage of several service systems:

Trucks	fork lift trucks	warehouses	transport packaging
- fuel	- electricity	- energy	- energy
- labor	- labor	- labor	- labor
- equipment	- equipment	- buildings	- materials

The case: LCA on Transport Packaging

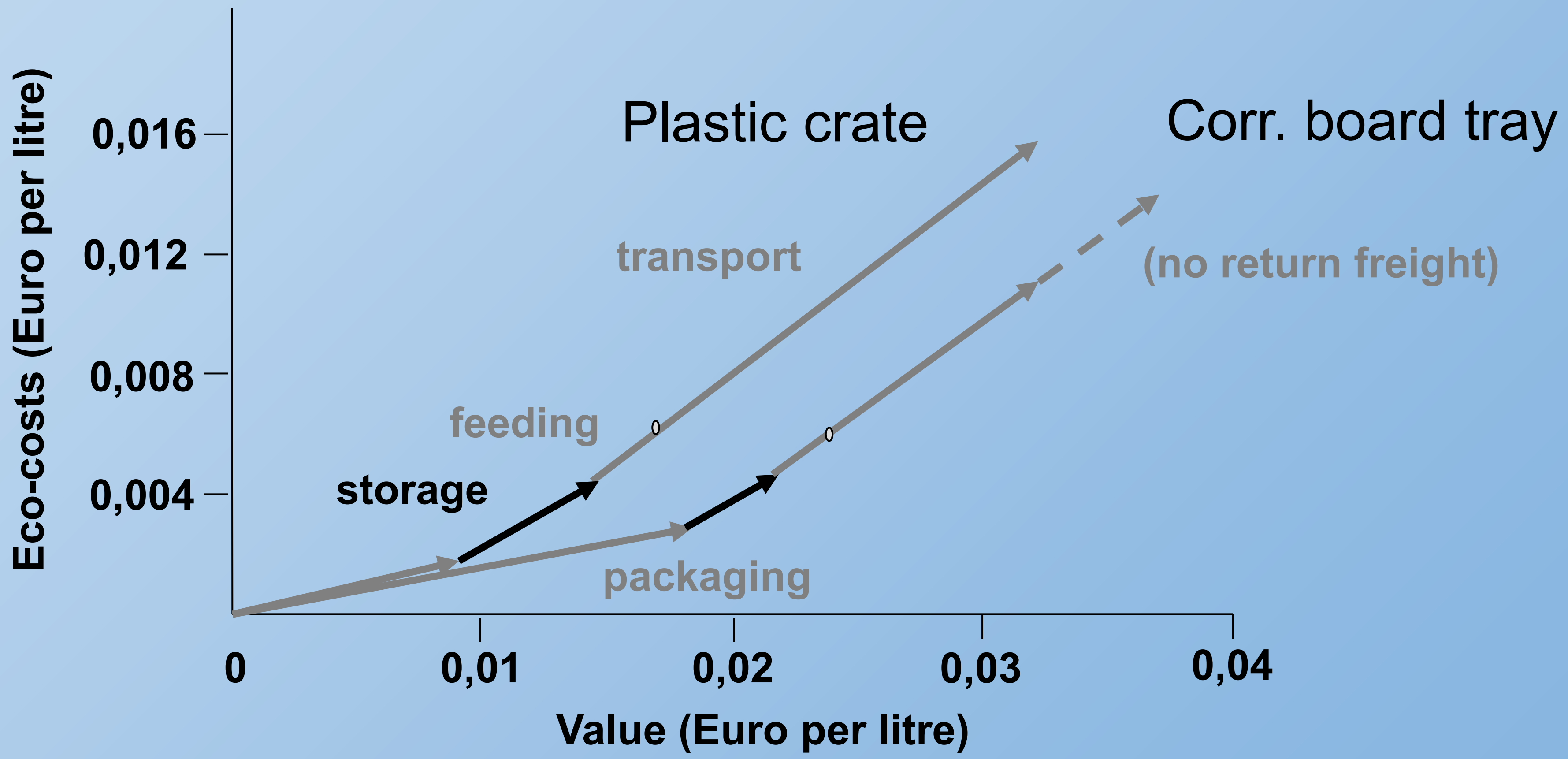
the key to low eco-costs is transport efficiency

Full-load Truck+trailer (26 pallets, distance 500 km)

	Corrugated BOXES	Plastic CRATES
Litres per pallet	2670	2196
Litres per truck	69.420	57.096
Eco-costs of:		
- truck+trailer (€/km)	0,31	0,31
(80% diesel incl CO_2, 10% rubber, 3% ad blue, 5% exhaust emissions)		
Subtotal (€/km)	0,31	0,31
Km full loaded t+t	500 + 500 * 0,3 = 650 km	500 + 500 = 1000 km
Eco-costs (€/trip)	202	310
Eco-costs (€/litre)	0,0029	0,0053

(green numbers are from the database)

The case: Transport of vegetables
from a Dutch greenhouse to a retail shop in Frankfurt
(FEFCO study, corrugated board tray system with 70% return freight)



Issue 1. the Functional Unit (and the declared unit)

essential to analyse that system A is better than B

FU = {system function} per {unit of calculation}
{plus optional: main scenario}

The “functional specification” of a system:
What? How much? How long? Which quality?

Declared Unit = {technical specification of product or service}
per {unit of calculation}
{plus optional: main scenario}

Examples of Functional Units:
- Transport, Communication
- a Car, a Chair, a Hand Dill, Coffee Machine

Examples of Declared Units:
- Wood, Steel, Electricity, Heat, Water
- also: a chair, a shoe (since they fulfil more than one function)

Issue 2. Transport data

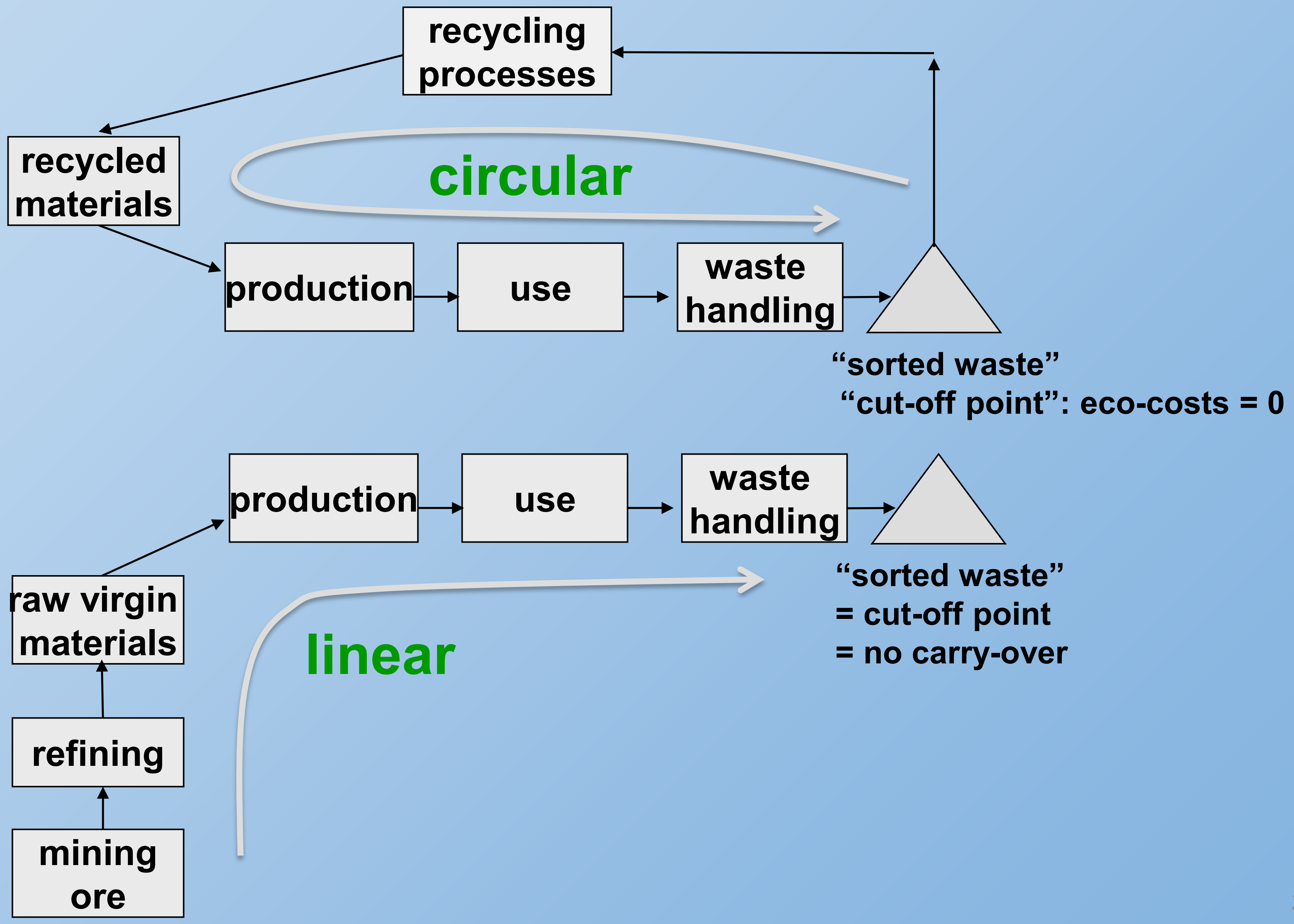
Idemat	freight > 320 kg/m3	freight < 320 kg/m3
Truck with trailer	ton.km	m3.km

Idemat	freight > 414 kg/m3	freight < 414 kg/m3
Truck with container	ton.km	m3.km

Idemat	freight > 414 kg/m3	freight < 414 kg/m3
Container ship	ton.km	m3.km

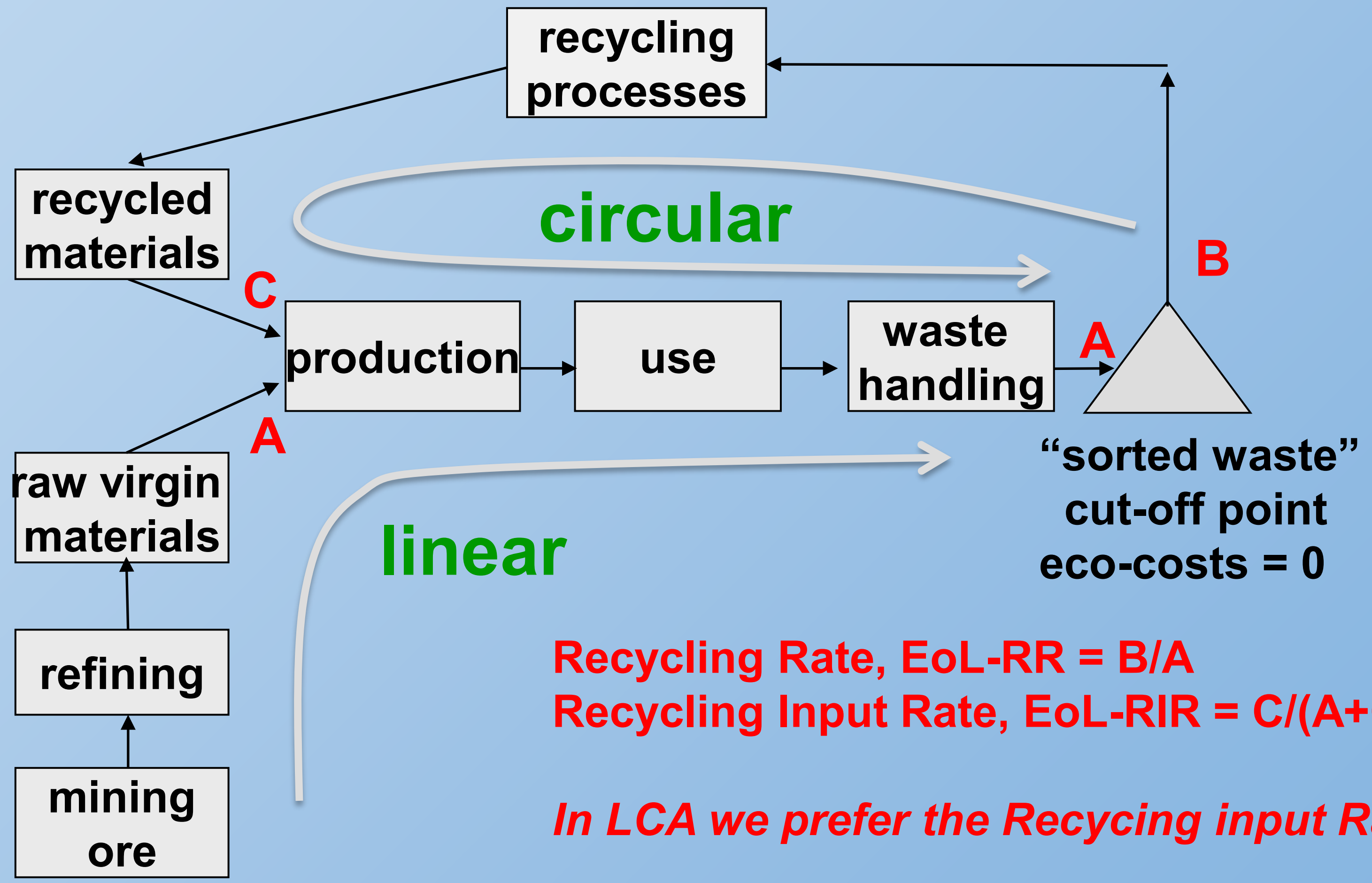
Idemat	freight > 167 kg/m3	freight < 167 kg/m3
Air freight	ton.km	m3.km

Issue 3: Recycling and the "cut-off point", in theory



Issue 3: Recycling and the "cut-off point", in practice

the "recycling rate" and the "recycling input rate"



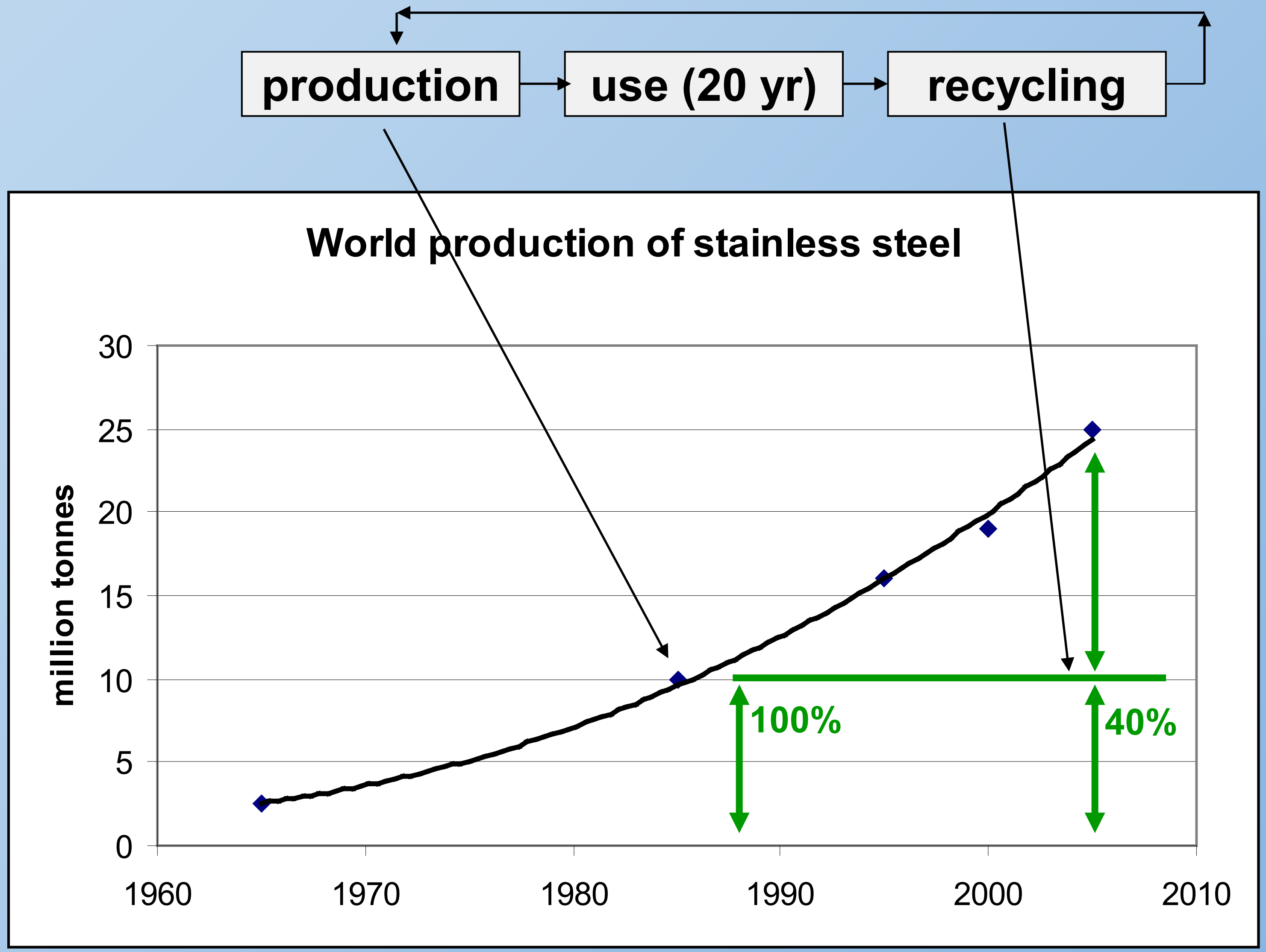
Recycling Rate, EoL-RR = B/A
Recycling Input Rate, EoL-RIR = C/(A+C) = recycling content

In LCA we prefer the Recycing input Rate,

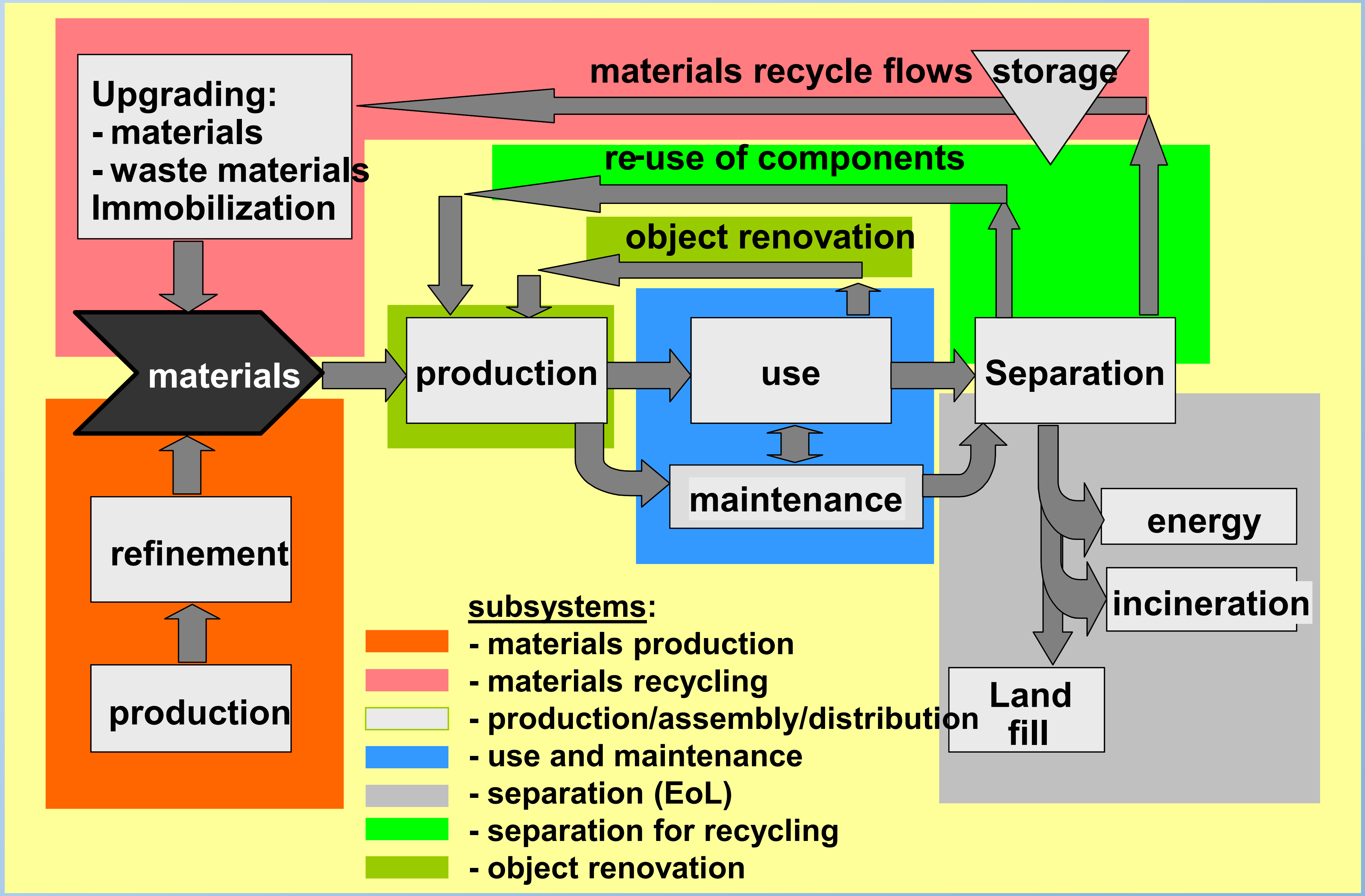
Issue 3: Recycling and the "system stock"

The residence time issue:

the "recycling credit", based on the RR, is often wishful thinking

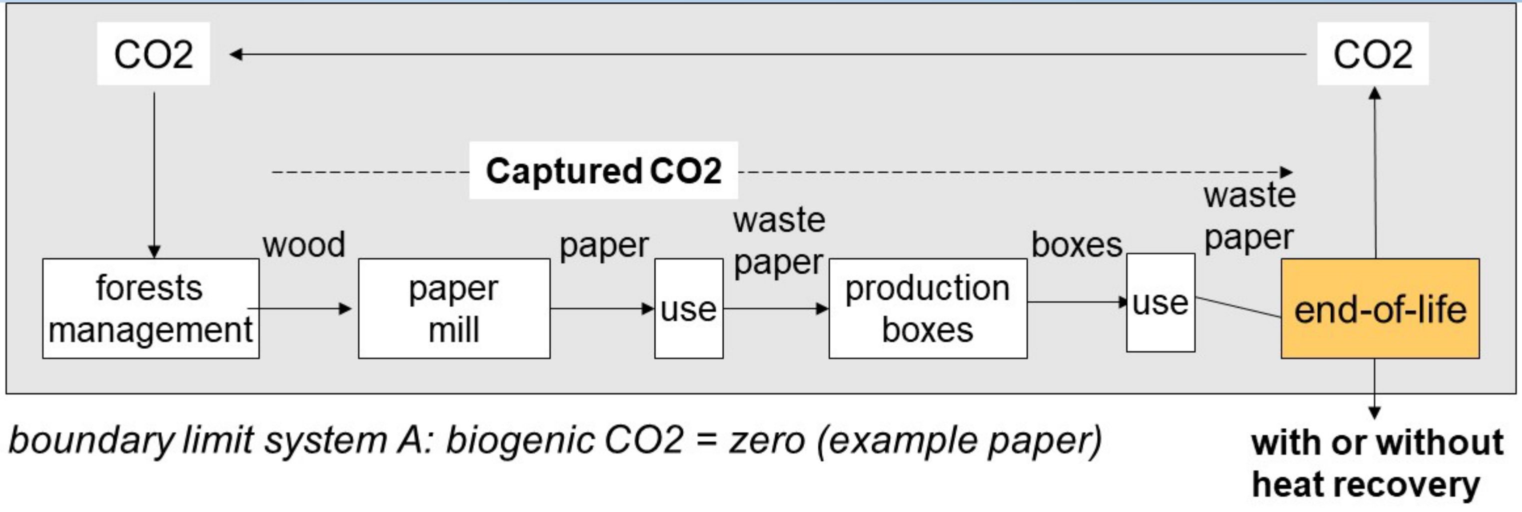


The basis of LCA calculations on tangible products

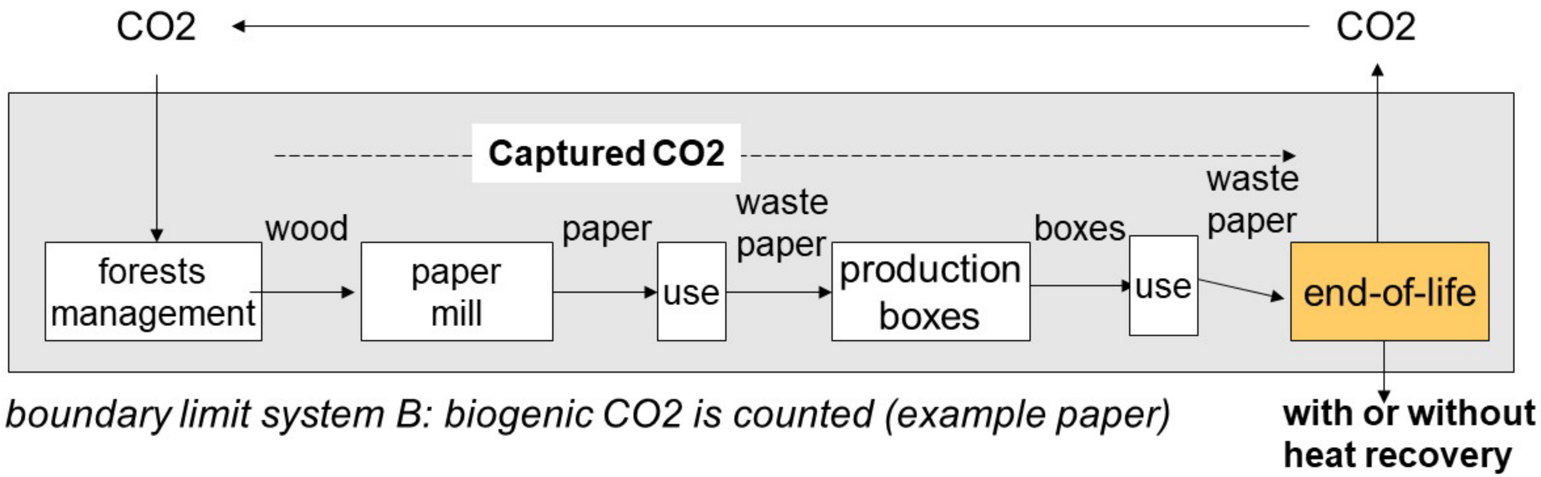


Issue 4: carbon sequestration (carbon storage)

The mass balance of biogenic CO_2: two approaches in LCA



boundary limit system A: biogenic CO2 = zero (example paper)



boundary limit system B: biogenic CO2 is counted (example paper)

System A is preferred by scientist: Biogenic CO2 = 0 i.e. not counted for life span < 100 years

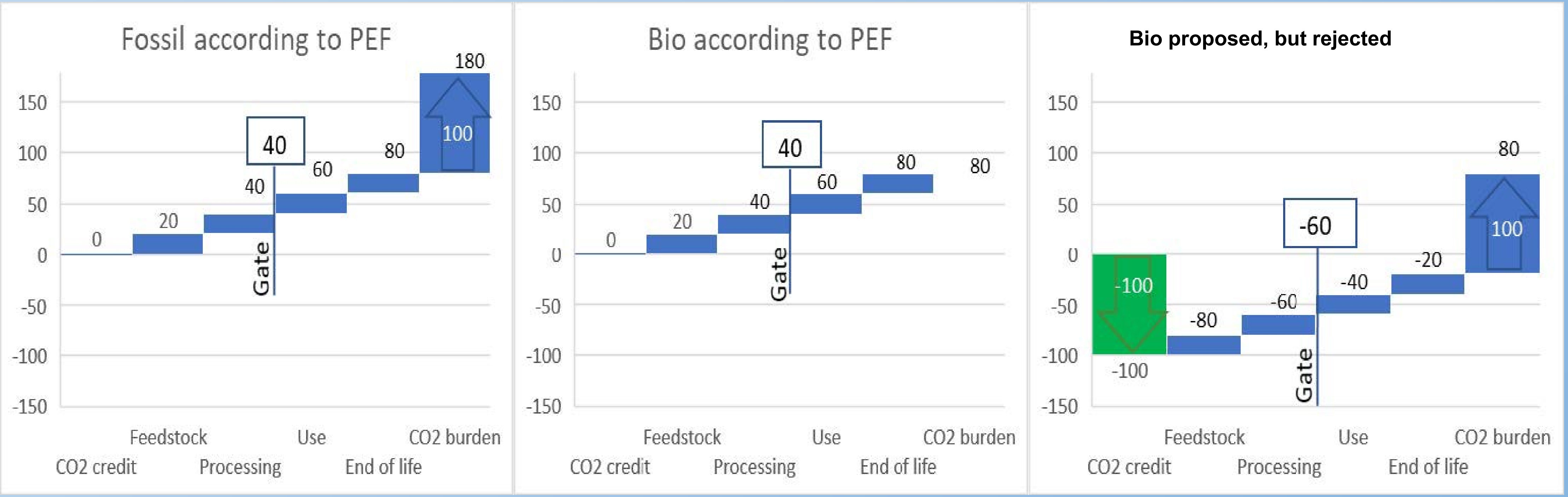
System B is preferred by the industry

Issue 4: carbon sequestration (carbon storage)

The mass balance of biogenic CO2: two approaches in LCA

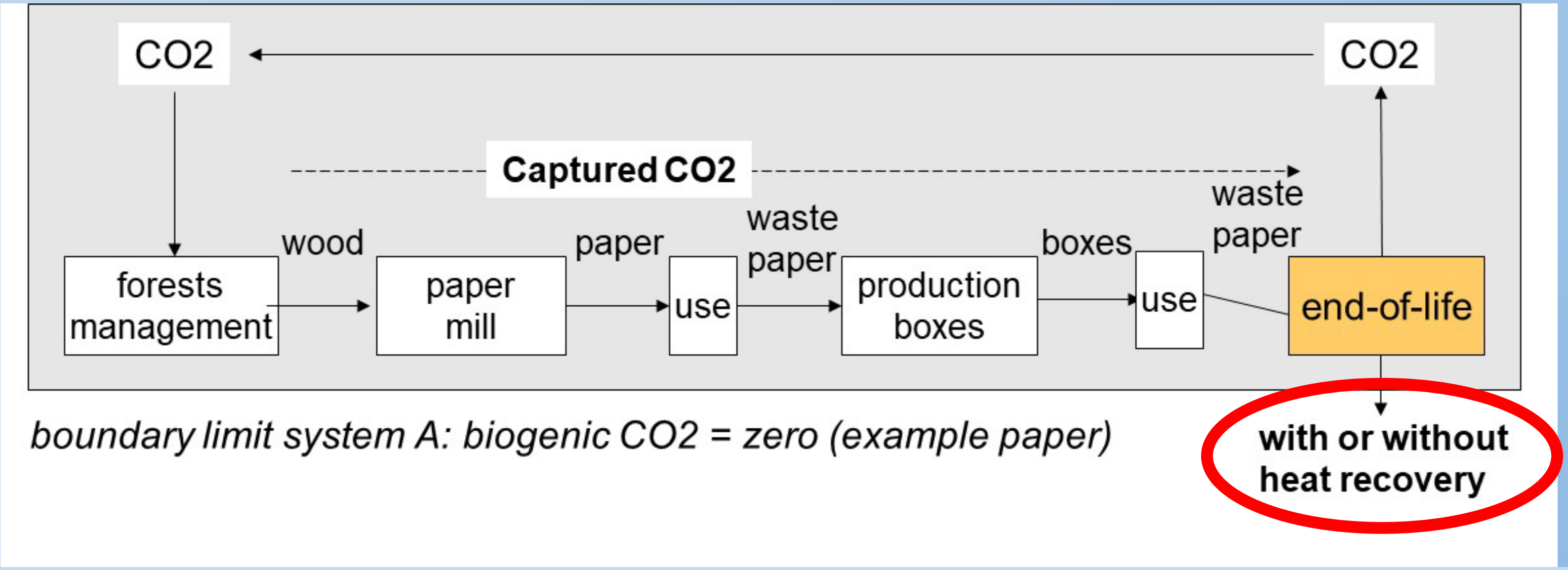
System A is preferred
by science,
since B is a form of greenwashing

System B is preferred
by the industry, since its negative
cradle-to-gate score: “carbon negative”.
but a form of greenwashing



Issue 4: carbon sequestration (carbon storage)

The consequences of the biogenic CO2 = zero approach (system A)

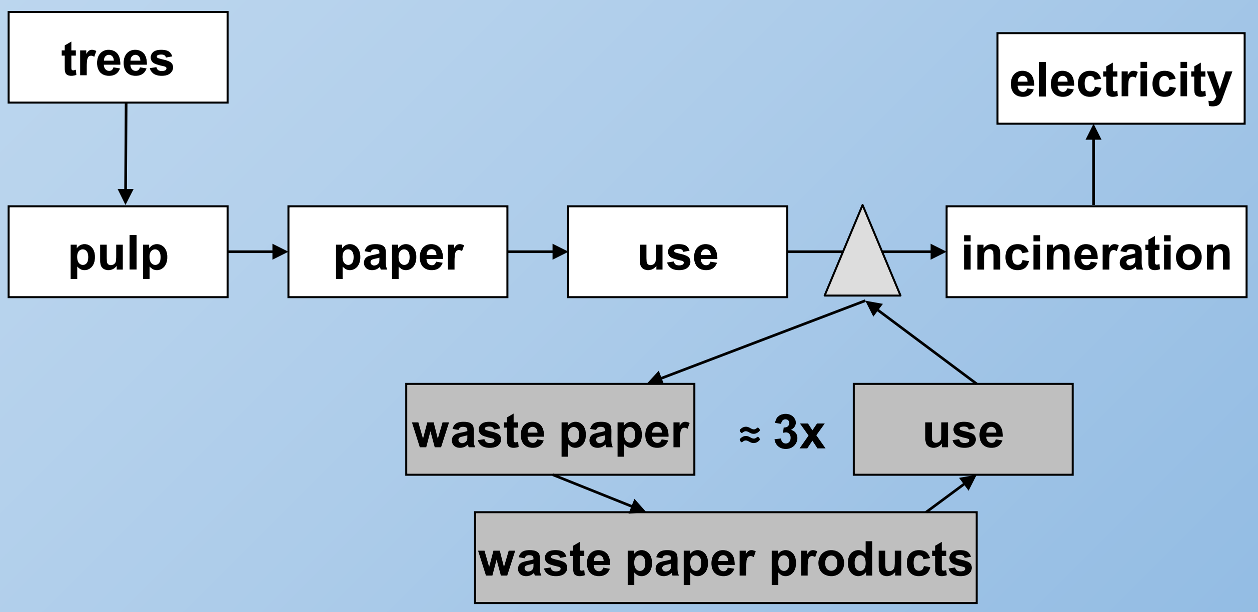


For combustion *with heat recovery* (i.e. power plants, or municipal waste incineration): eco-costs and carbon footprint are negative

under the condition that trees are:

- **from Scandinavian (boreal) forests,** since they are replanted
- **from FSC wood from tropical forests** (rotational harvesting and reduced impact logging)
- **not from traditional "clear cutting" in tropical forests**

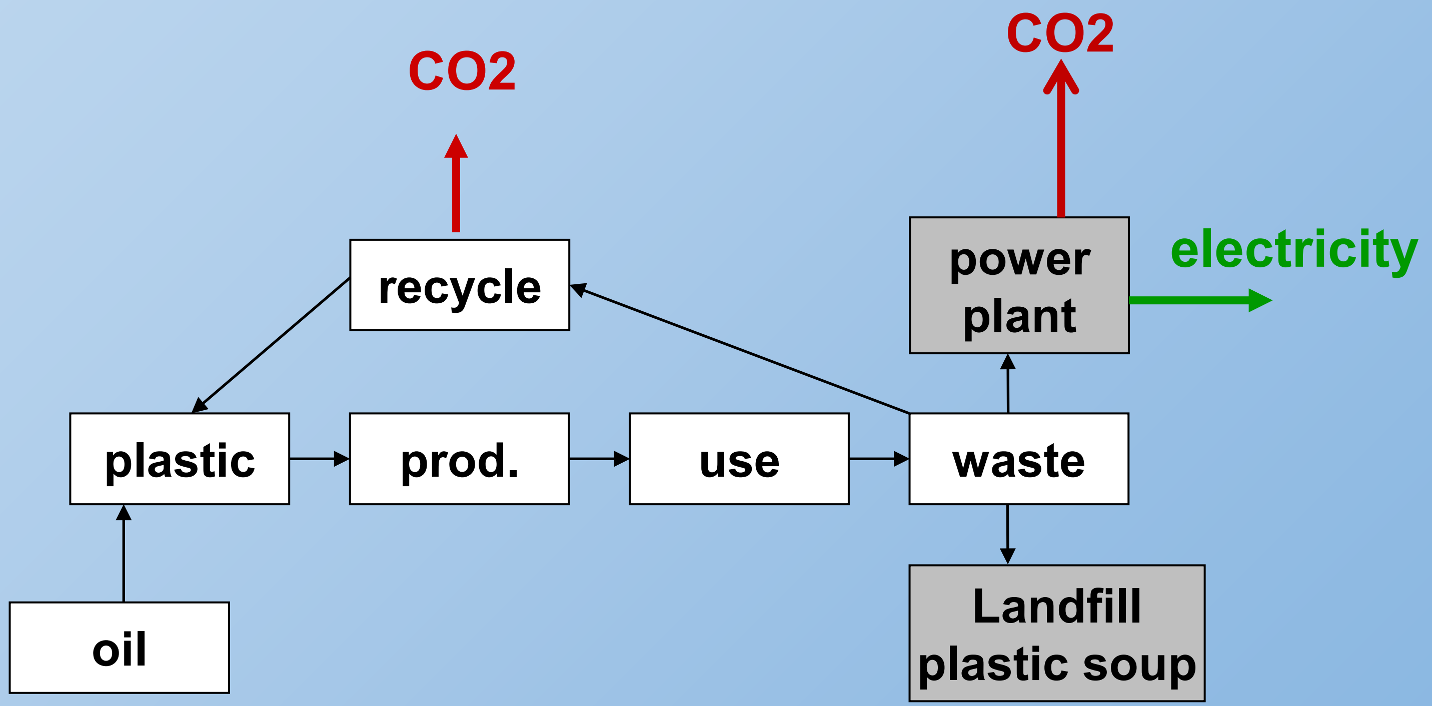
Issue 5. “Downcycling” e.g. Paper



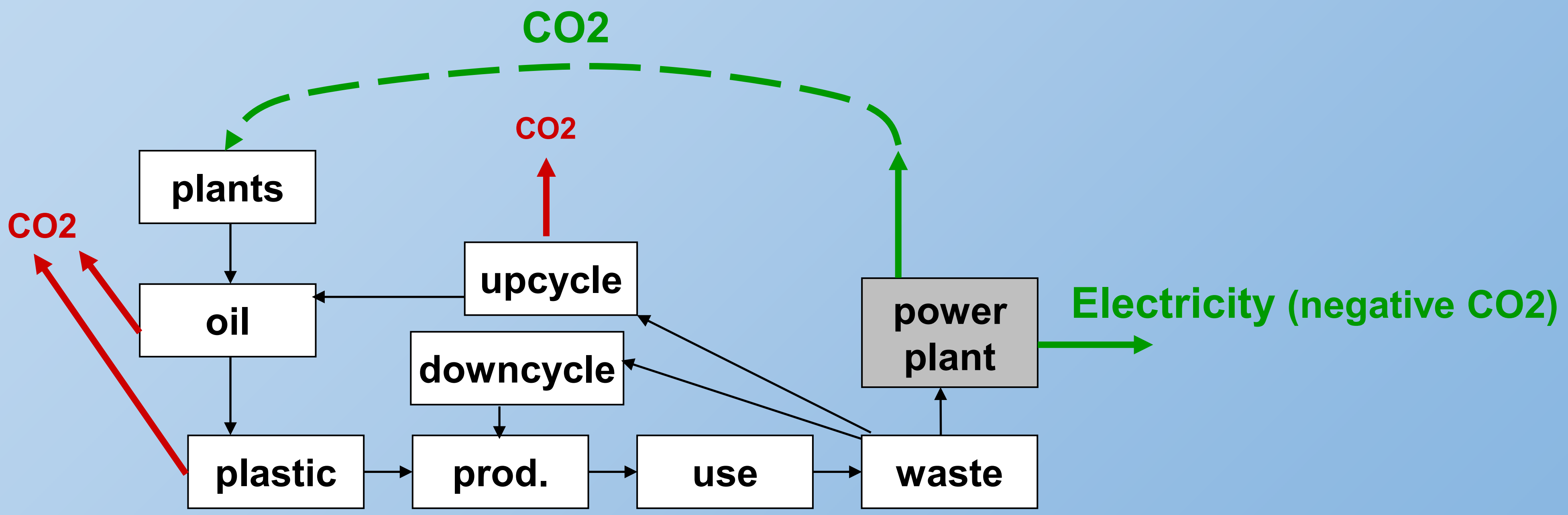
Note 1: data: recycling in the EU 71.4% -> 2.5x, in USA 68% -> 2.1x
in the Netherlands 79% -> 3.8x (Milieu Centraal)

Note 2: allocation of the benefit of incineration is rather arbitrary
apply a percentage that “makes sense”
(e.g. food packaging 90% to incineration,
books, newspapers, magazines 90% to recycling)

Issue 6. Fossil based plastics have no positive end-of-life



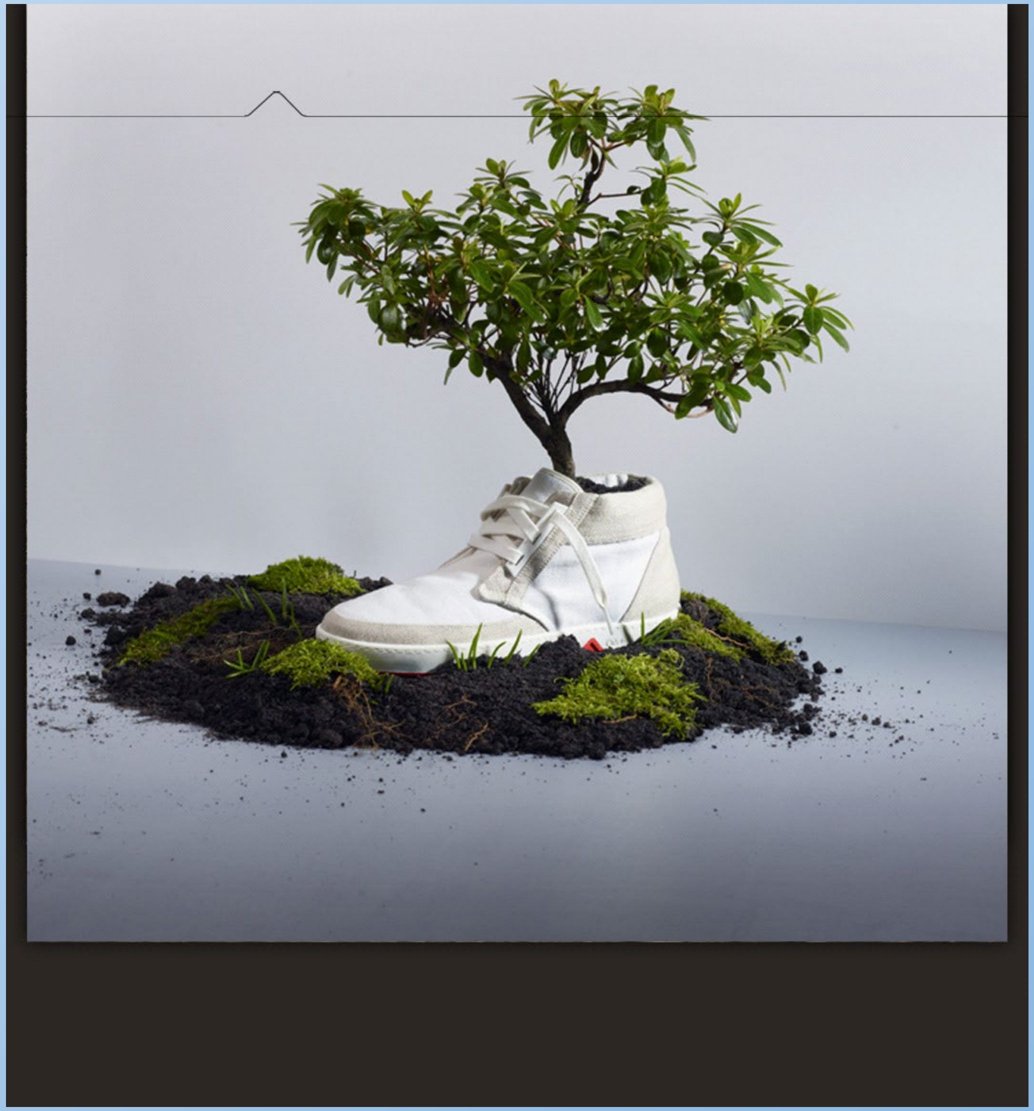
Issue 6. Bio-based plastics have a positive end-of-life score in combustion 'with heat recovery'



Note 1: In LCA, biogenic CO_2 (short cycle) is not counted (as wood, according the IPCC)
the electricity production is causing negative carbonfootprint in the calculation

Note 2: Downcycling = mechanical recycling, Upcycling = chemical recycling

Issue 6. Composting scores in marketing better than combustion and recycling. How about the facts?

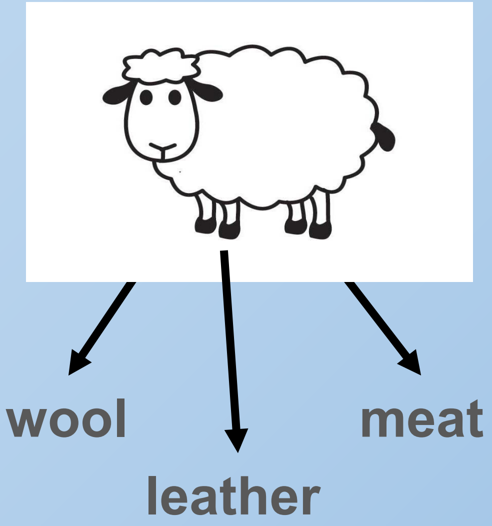


OAT shoes

Issue 7. Economic allocation of products and co-products

PROBLEM: How to distribute the eco-costs of the total eco-burden?

SOLUTION: Use the percentages of financial turnover



Example:

Wool	50% of the total turnover
Meat	45% of the total turnover
Skin for leather	5% of the total turnover

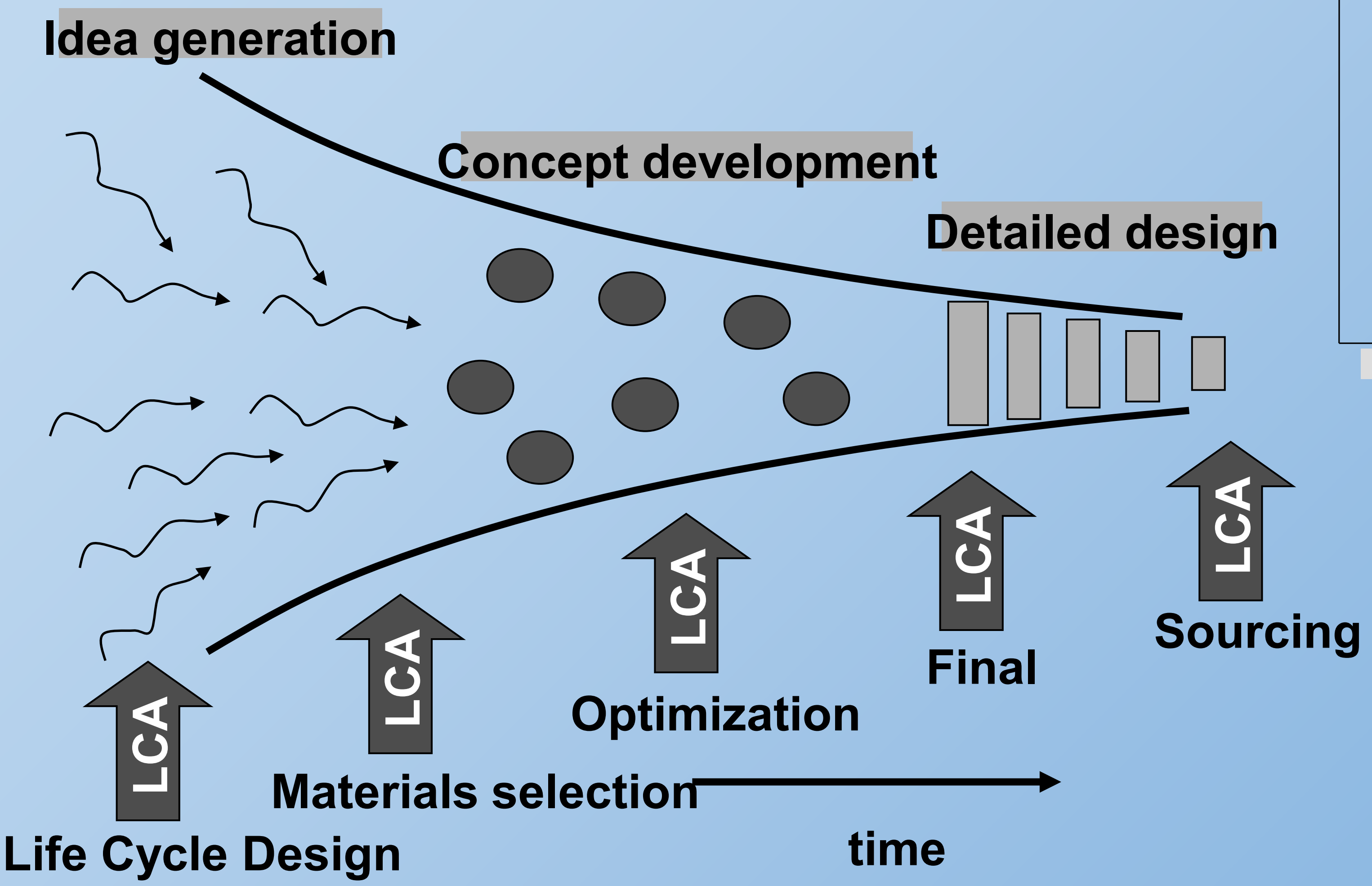
The total impact will be distributed:

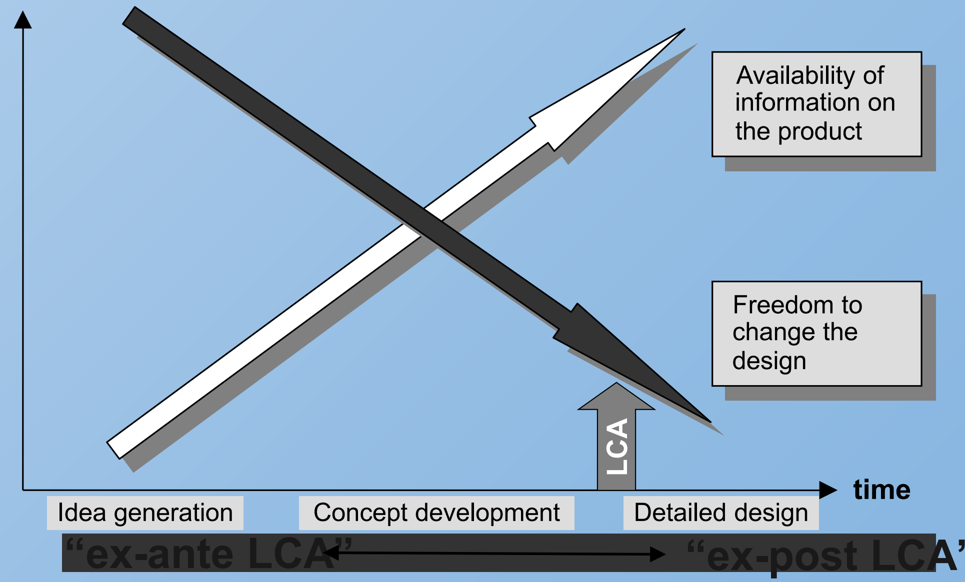
Wool	50%
Meat	45%
Skin for leather	5%

Note: mass allocation leads generally to greenwashing of the main product

Issue 8. the issue of accuracy in LCA, versus impact

On what development stage do you want to focus? (check alternatives prior to your choice)





Your Assignment:

Question 1 (answer this question on your own)
With regards to the batteries:
calculate the gain inn eco-costs for "manufacturing total" when you replace MNC811 by FLP?
(keeping the total weight constant by more AL components)

Question 2 (answer this question with your project group)
With regards to Aluminium:
what is your opinion on replacing carbon steel by strong alloys like chromium - molybdenum steel? Carbon or Aramid fibre? Or anything else?

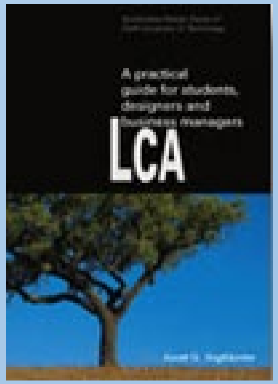
[the car](#) [the tool](#)

LCA documentation of at the Delft University of Technology

BSc students

from **“how to do it”**

by
- taking way unnecessary complexities
- providing readable text with examples
- providing data in an easy assessable form



MSc students

to **“what to do with it”**

by giving guidance in
- what to do in which design stage
- what to do in which product portfolio position