

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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2023

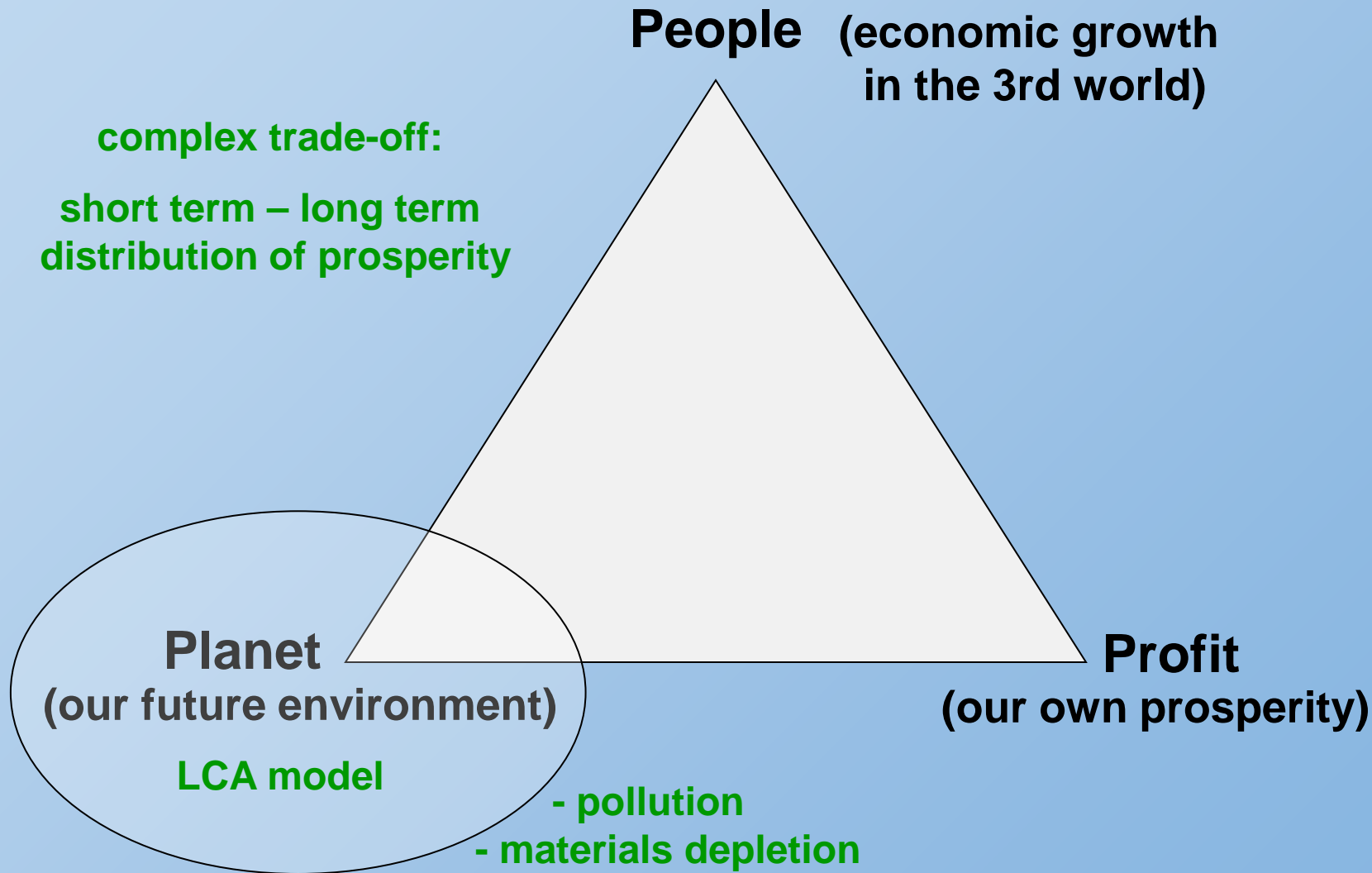
The Issues in the first lecture:

- 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.”

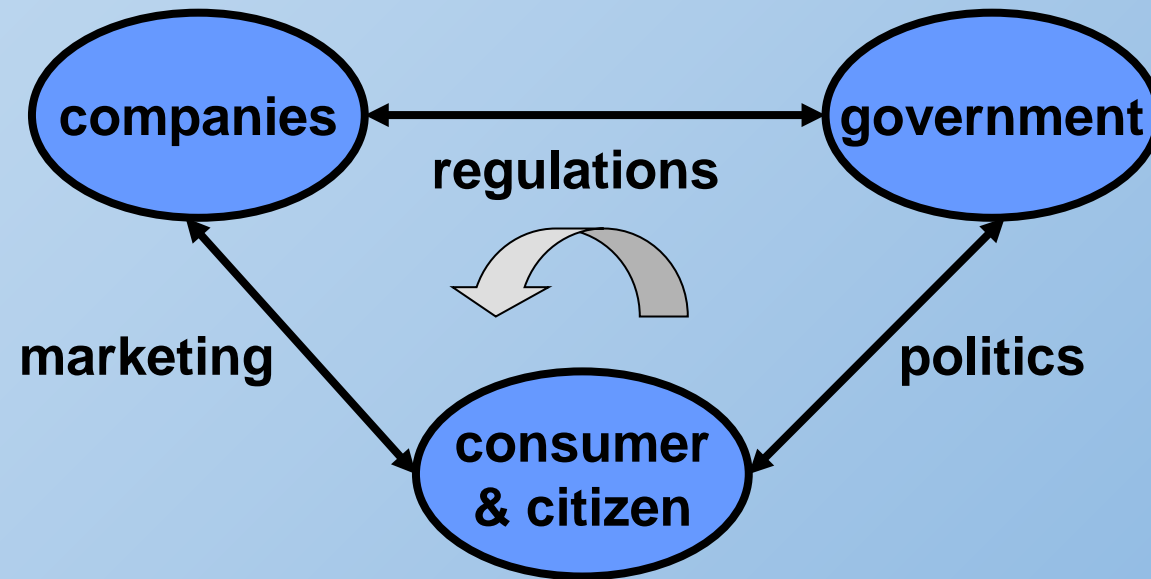
(Brundtland, 1987)

**“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’
↓

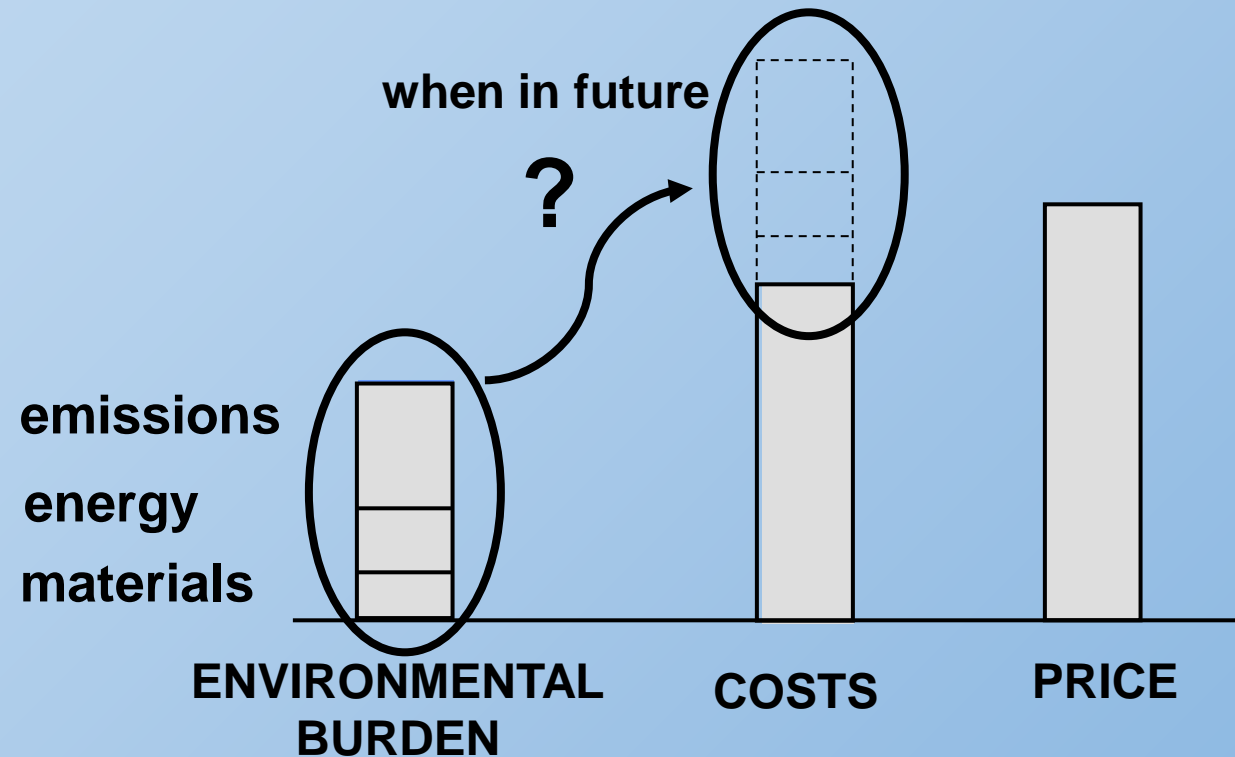
Interaction of the 3 stakeholders on the road towards sustainability



The relevance for a company:

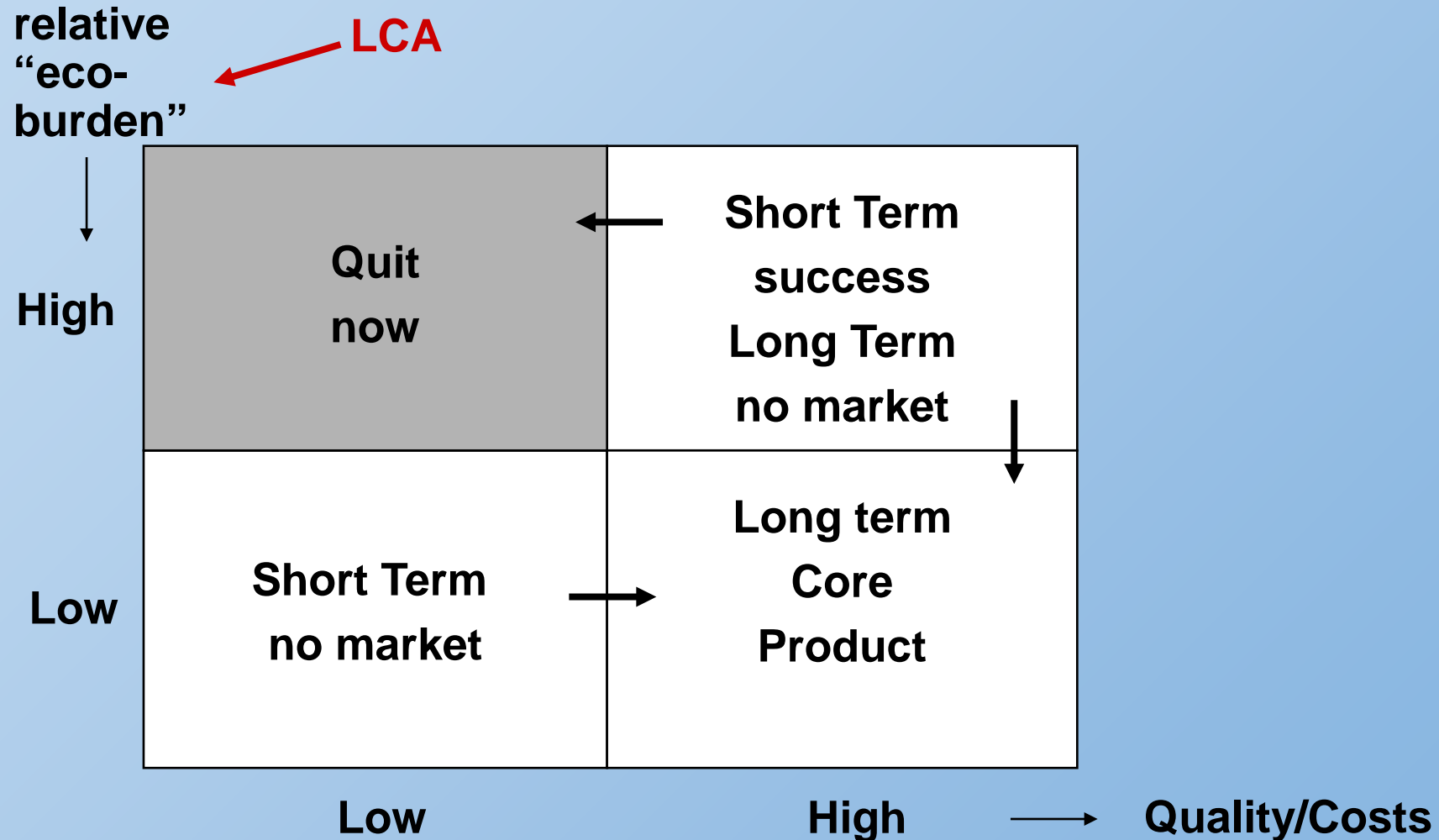
Environmental burden will gradually become internal costs as a consequence of governmental regulations*) !

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

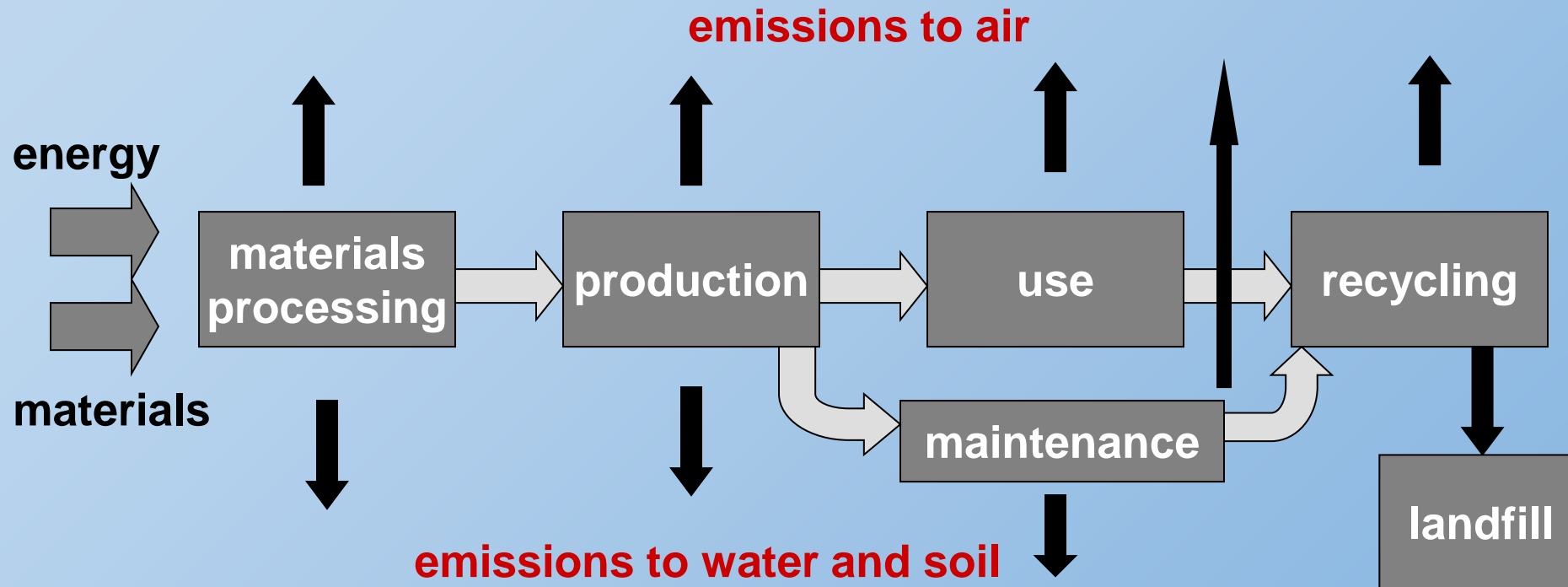
not reusable



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

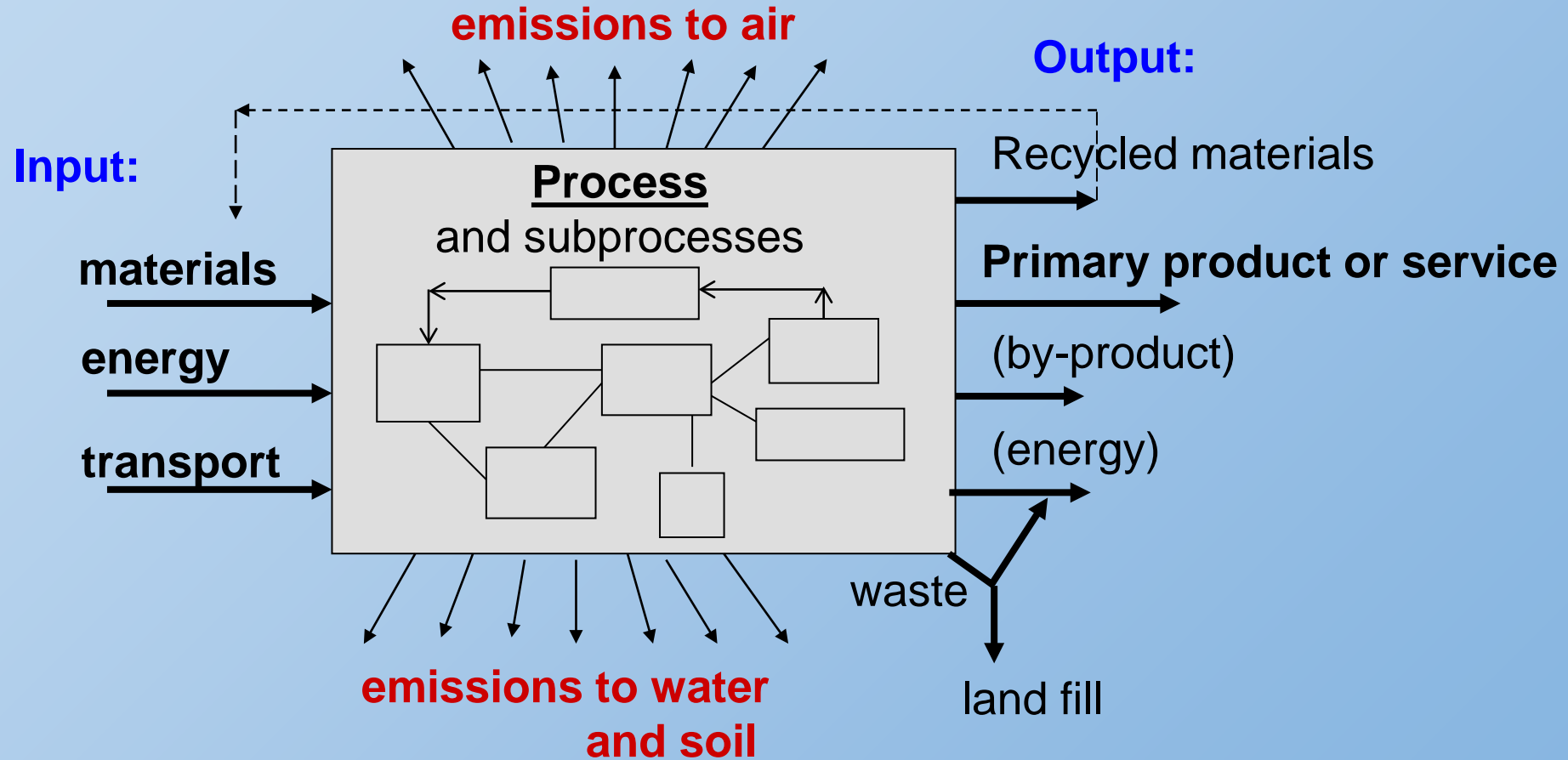


**An LCA provides data on the environmental burden
“from cradle to grave”**



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

Category

☒ Exclude long

☐ Skip unused

☐ 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: c

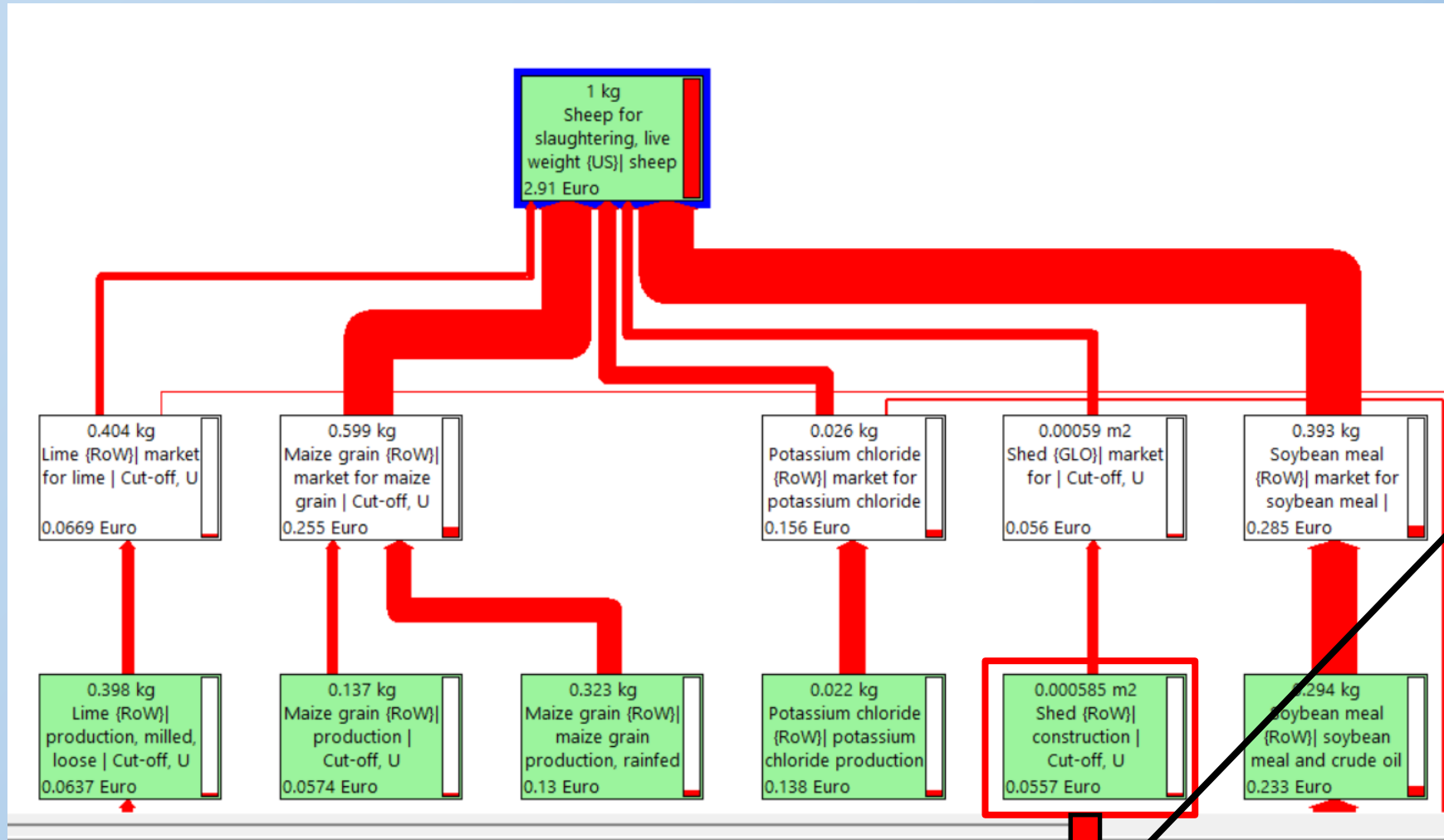
Example:

Sheep for slaughtering at farm gate

emissions to air and water
1832 (!) lines

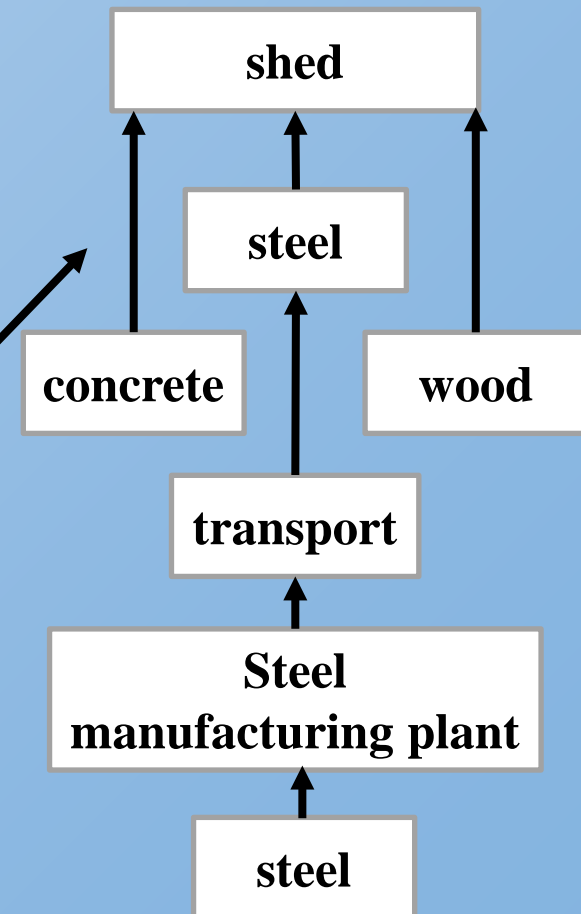
There are LCIs of 18000 (!) processes in the ecoinvent v3.8 database

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



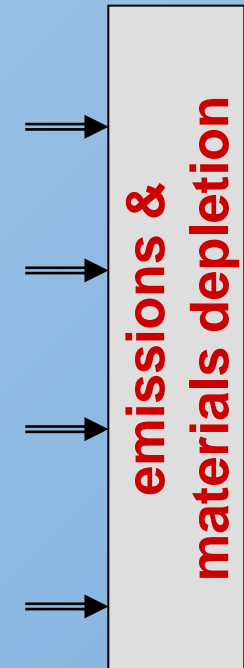
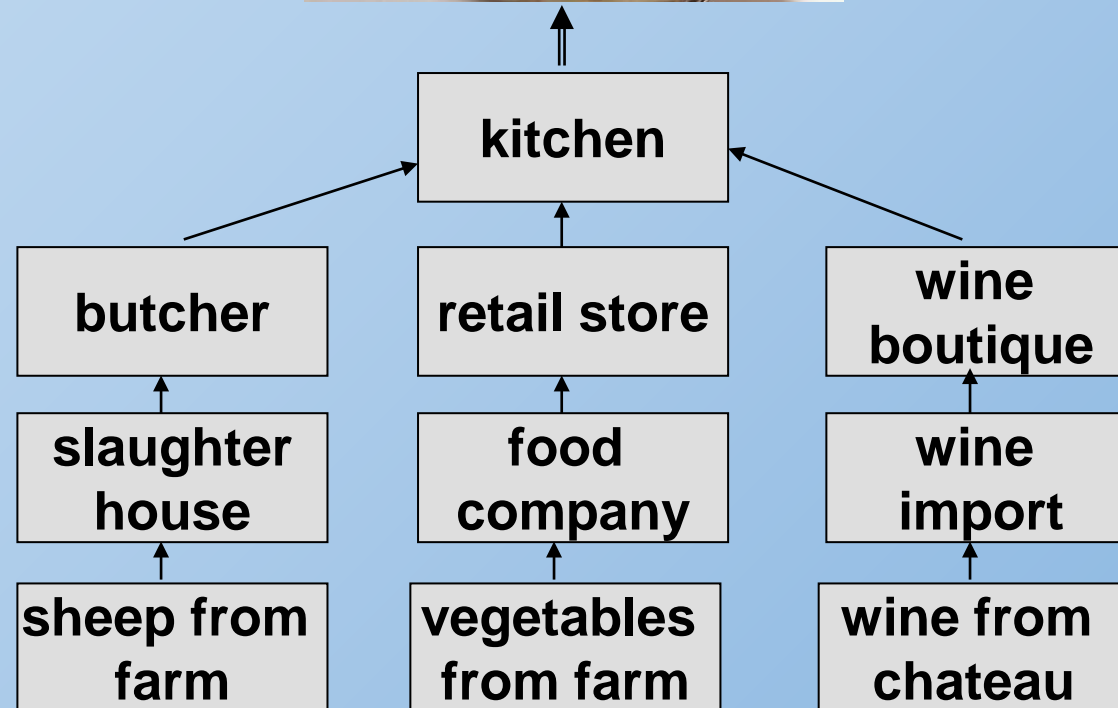
each block has its own “tree”

You can dig deeper and deeper, for instance:

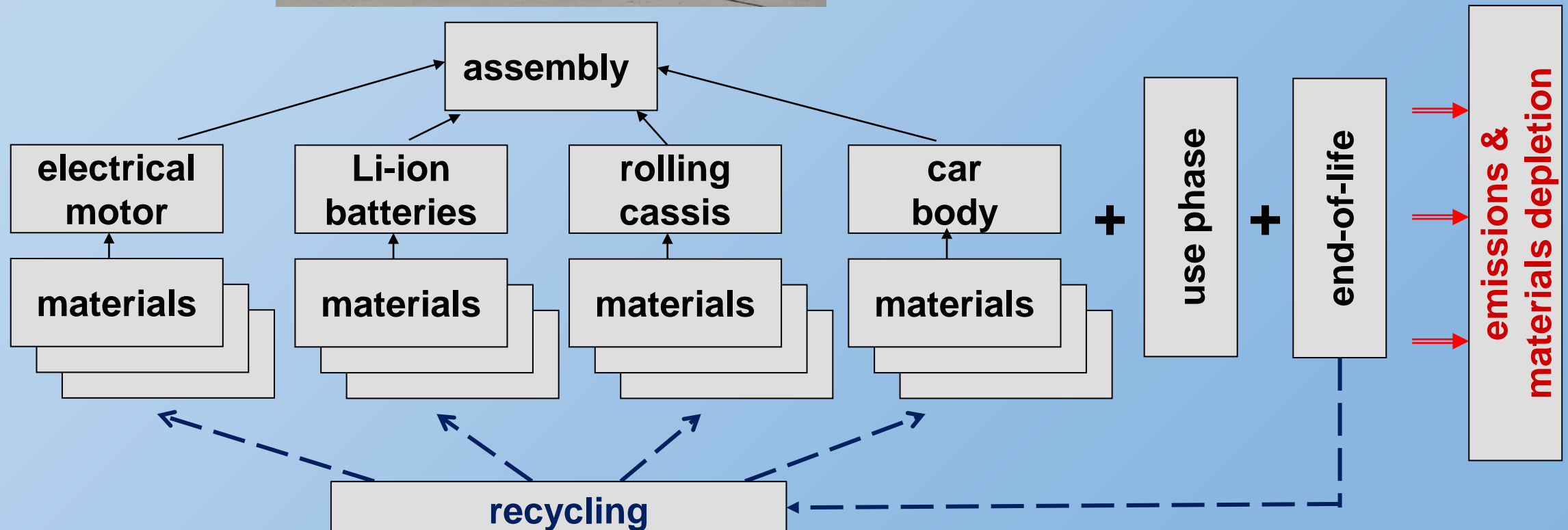


etcetera

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:

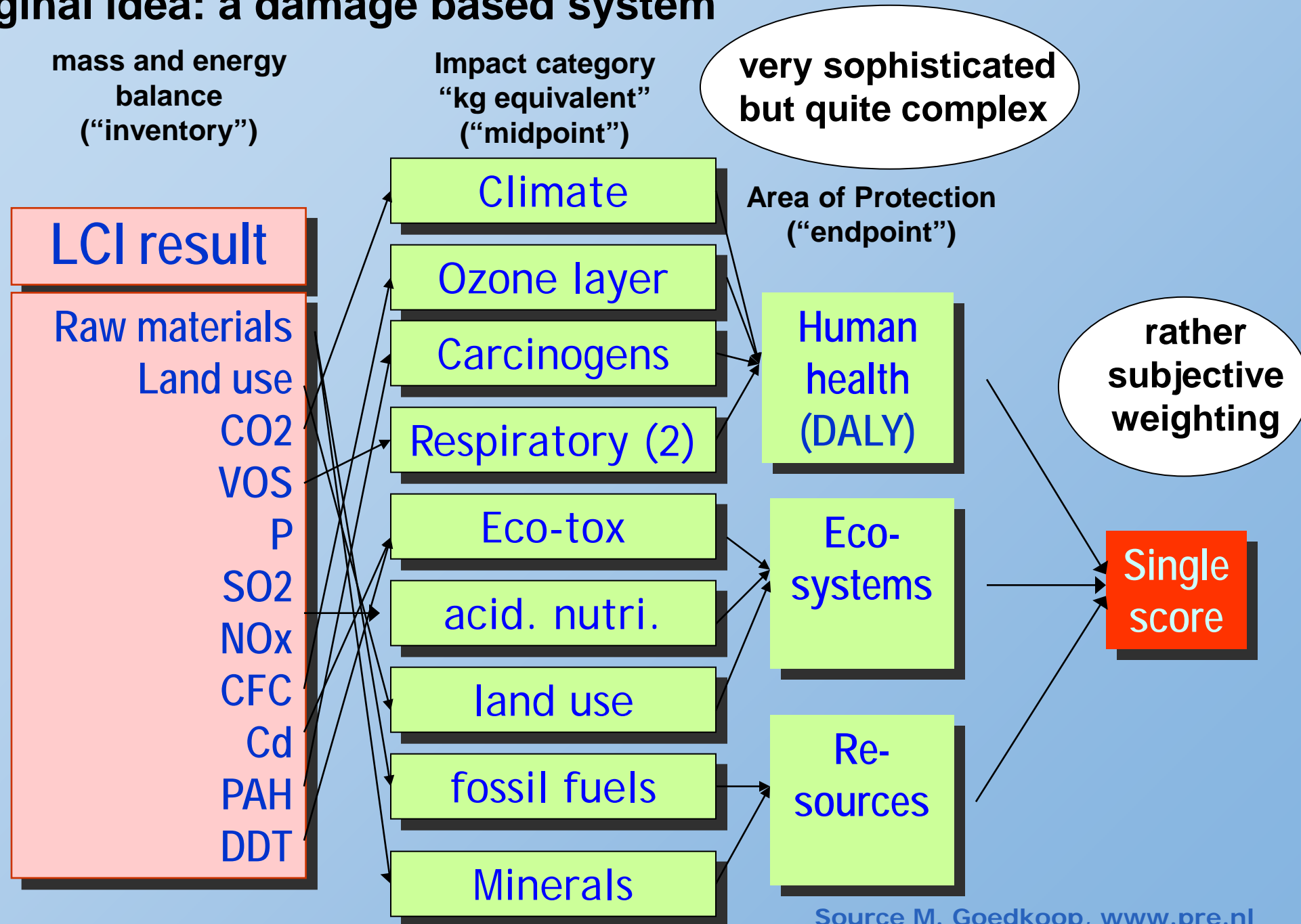
- based on 1 “single issue” **the Carbon Footprint (CO₂)**
- based on damage **the Recipe 2016 / Environmental Footprint**
- based on prevention costs **the Eco-costs 2023**

Which choice?

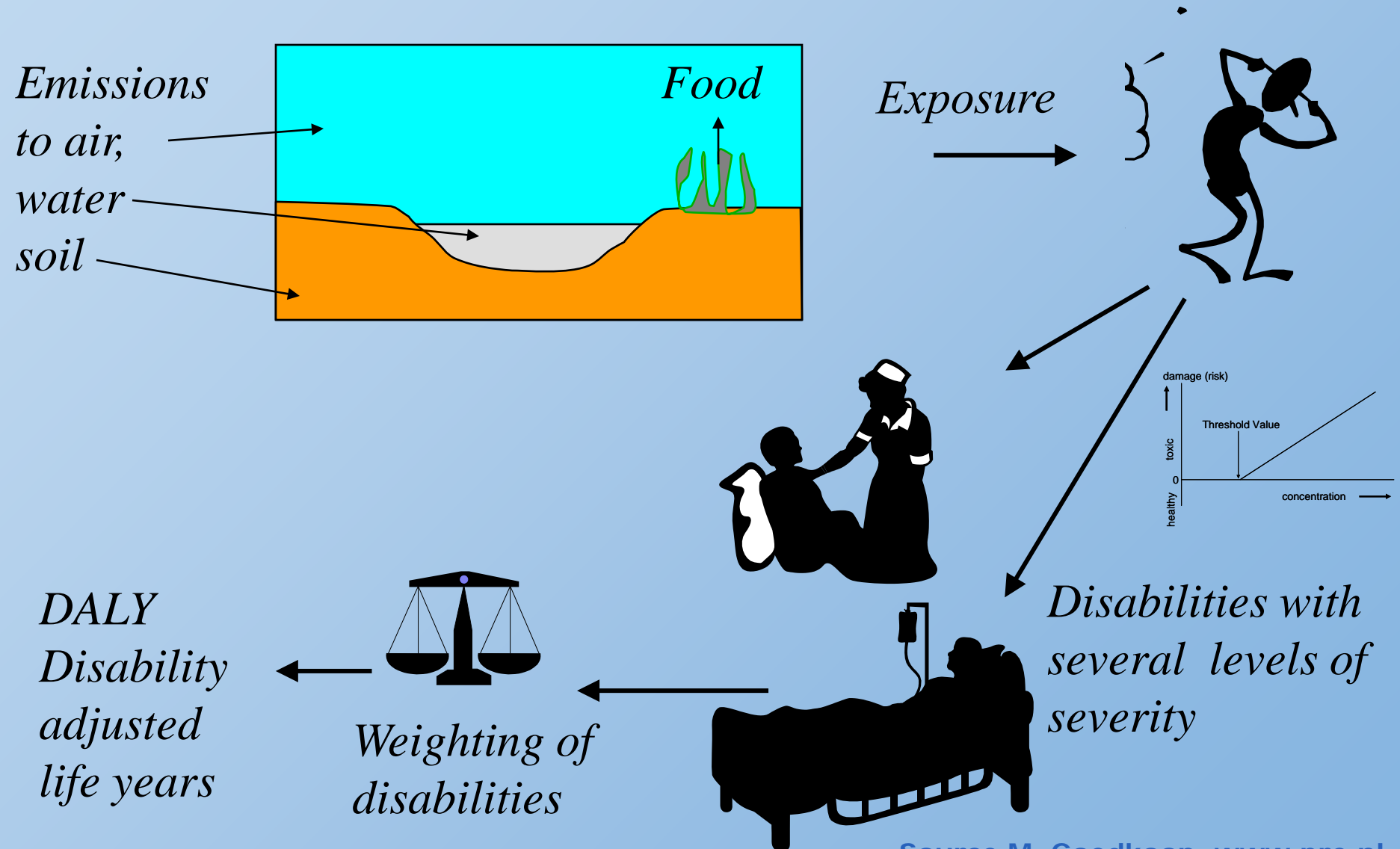
I recommend the eco-costs:

- 1. It includes toxicity (e.g. NO₂ and NH₃, 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. It is suitable for Cradle to Cradle calculations,
taking into account recycling (“closing the loop”)
(the Carbon Footprint is not suitable for C2C calculations)**

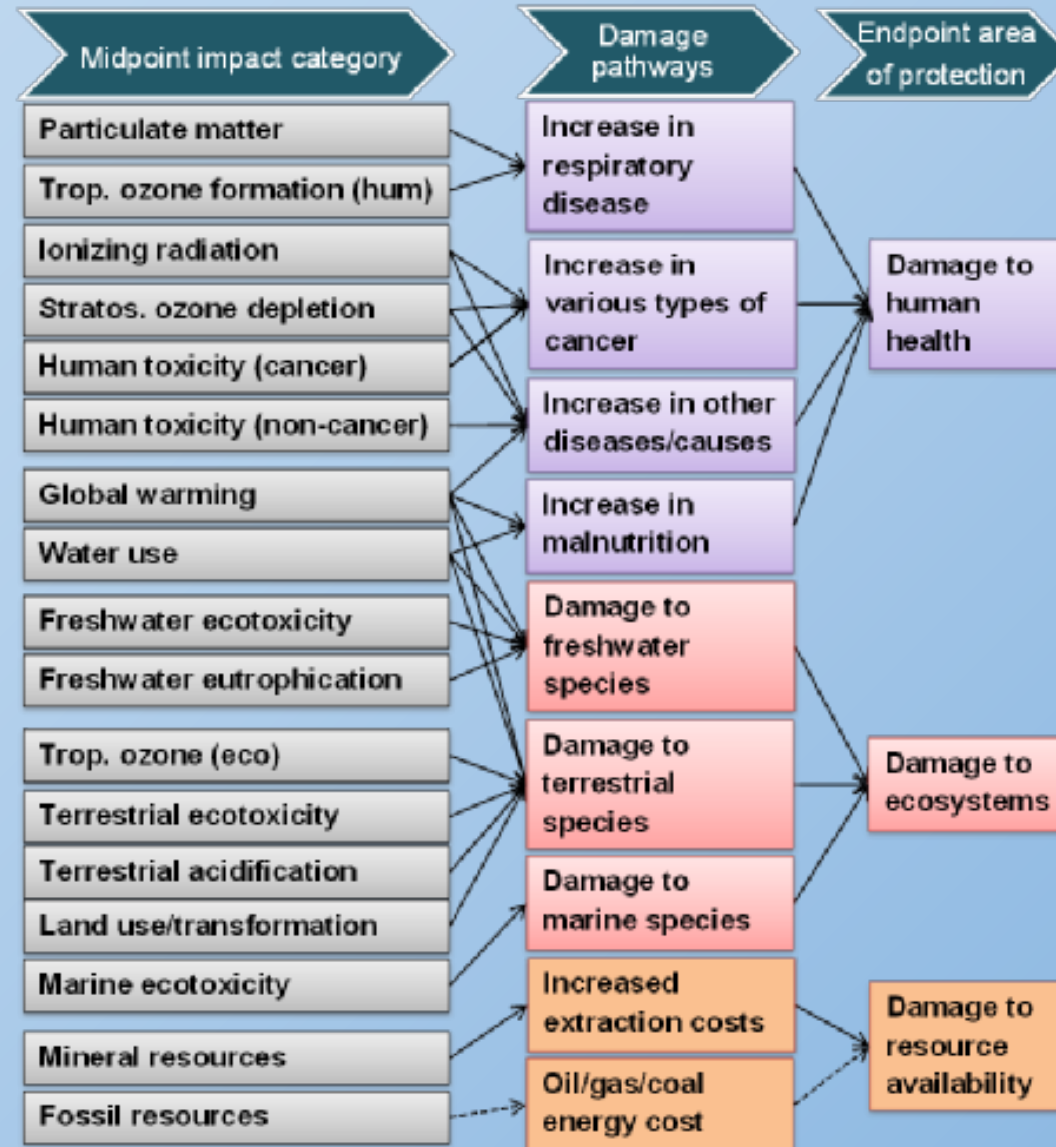
The original idea: a damage based system



From emissions to human health, a complex calculation

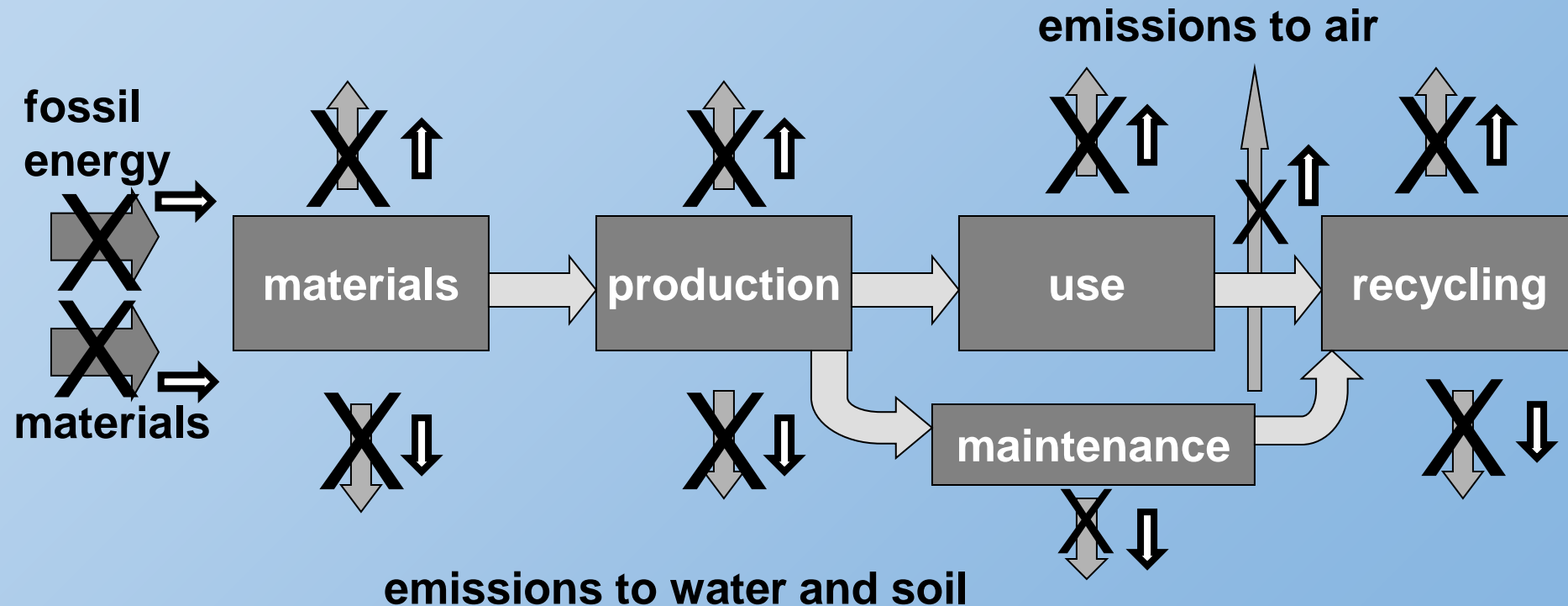


Recipe 2016, the best damage based system: even more complex, but better? (and still subjective weighting)

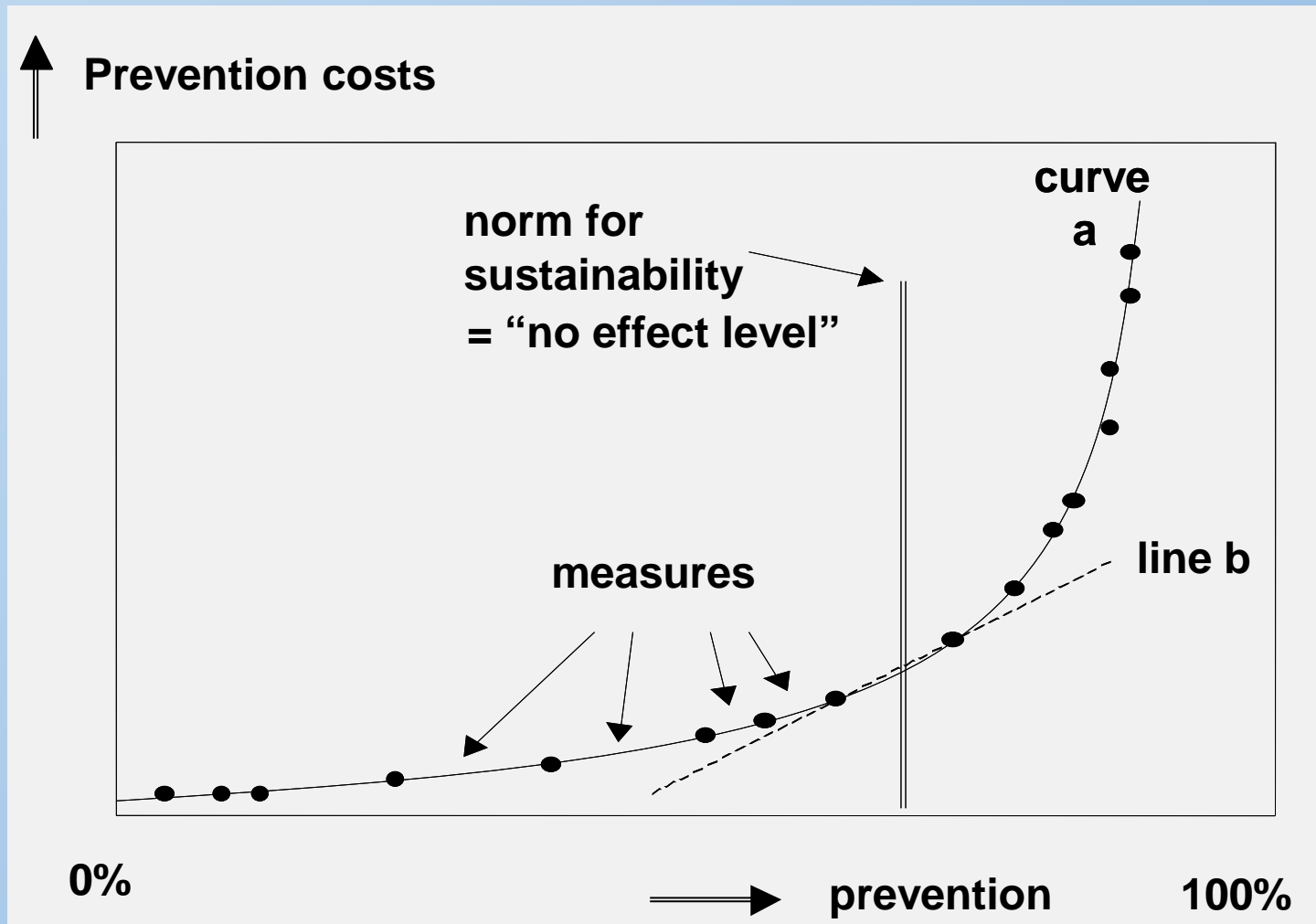


A total different concept: the Eco-costs 2022 based on the 'marginal prevention costs' (external costs, or “hidden obligations”)

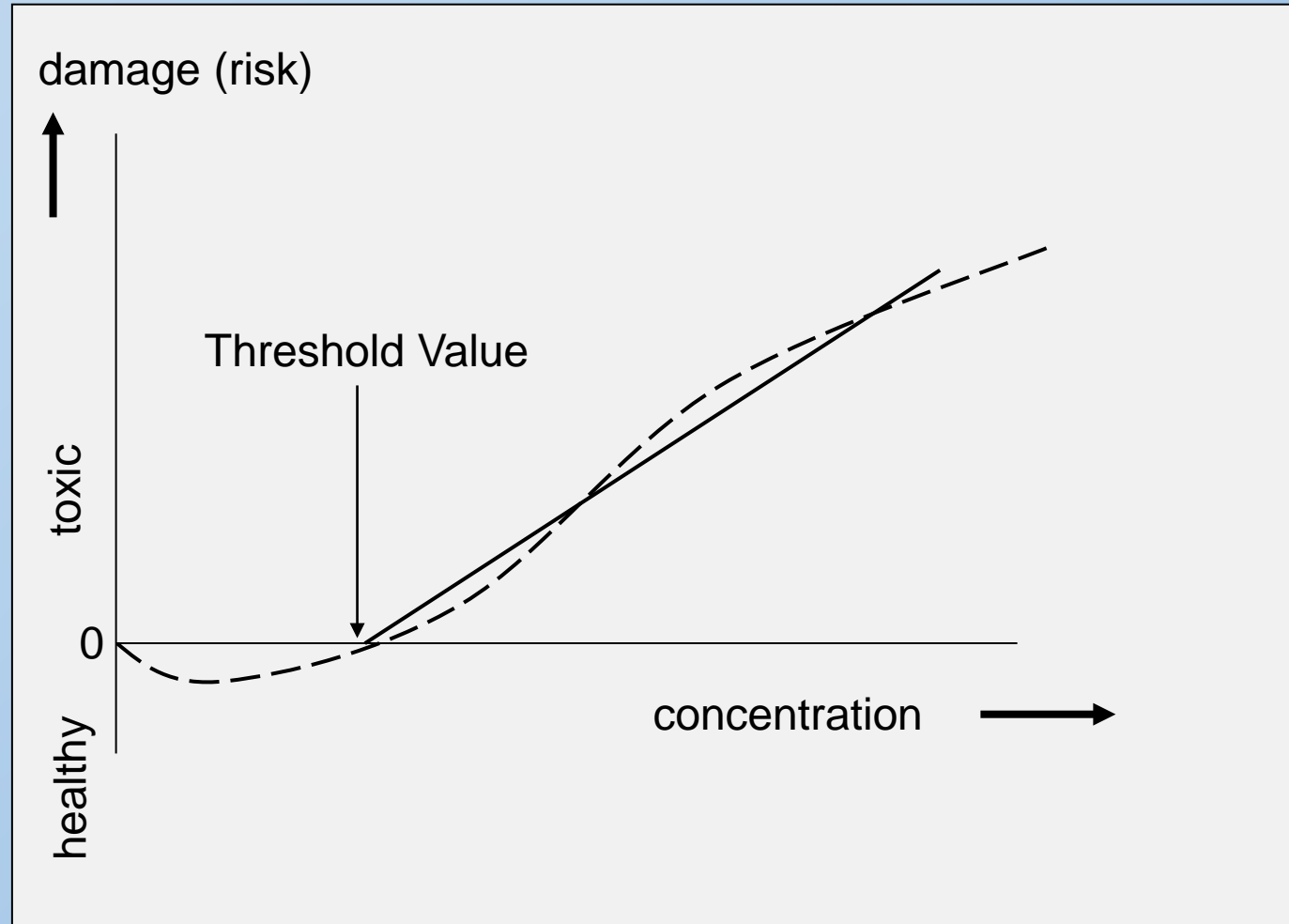
“the eco-costs are the costs of prevention measures,
which are required to reduce the current emissions,
to a sustainable level”



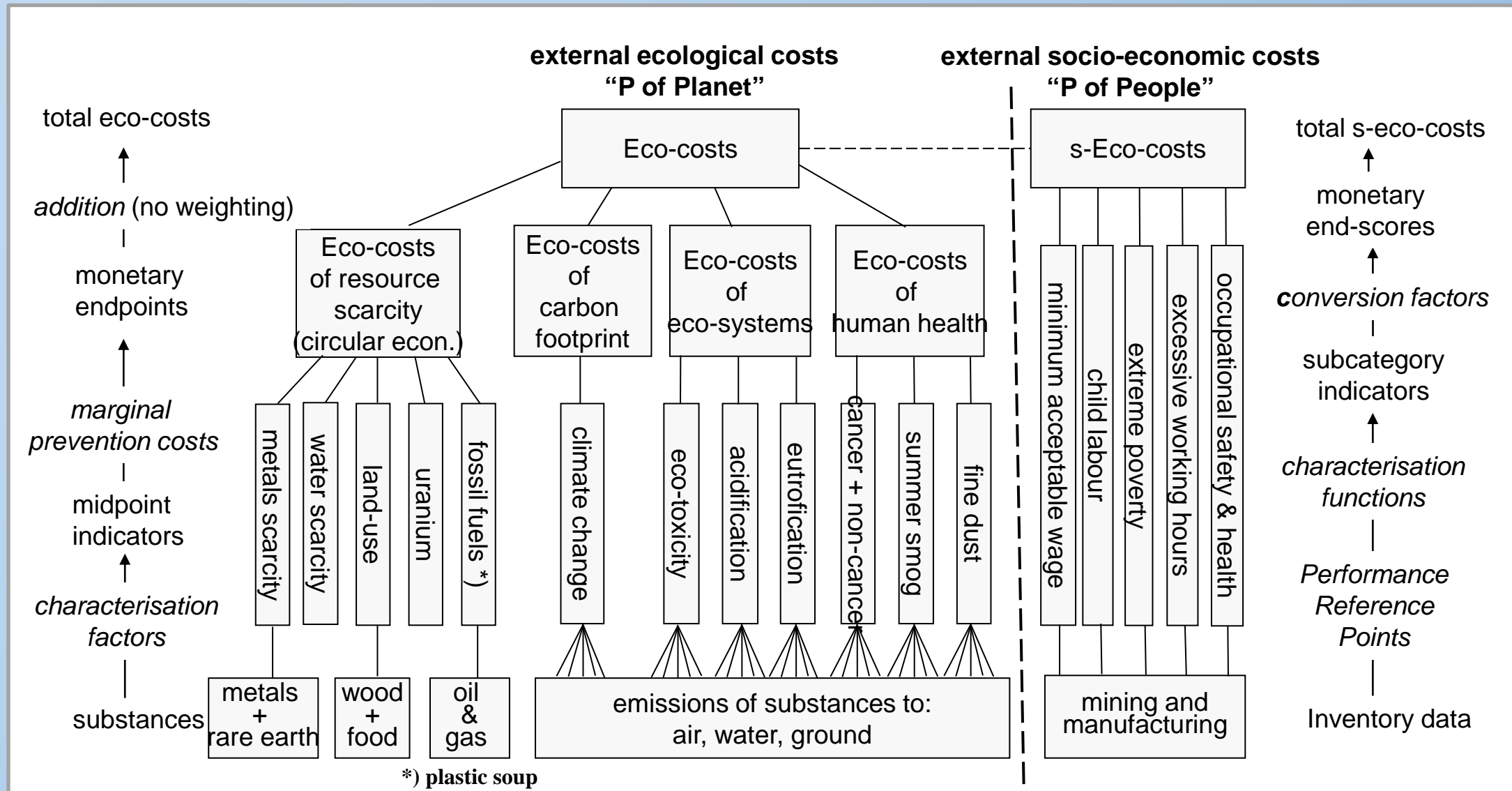
**Eco-costs are based on marginal prevention costs
at the “no-effect level”
(the costs in euro/kg of technical measures)**



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



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



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

kg CO2 equ / kg

example
greenhouse
gasses
in Simapro

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-2,5,8,11,14-pentaoxapen		173350-38-4	4240	kg CO2 eq / kg
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-tetraoxanon		188690-77-9	8580	kg CO2 eq / kg
Air		Dinitrogen monoxide		010024-97-2	298	kg CO2 eq / kg
Air		Methane			36	kg CO2 eq / kg

Eco-costs 2023:

1 kg CO2 equ =
0,123 €

For all midpoints: Eco-costs of more than 58.000 substances

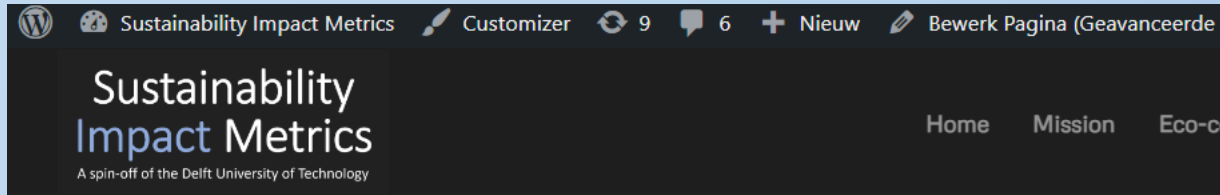
From classical LCA towards “Fast Track” LCA: = from big database manipulations towards “lookup tables”

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: <ul style="list-style-type: none"> - double counting (factor 2) - unnecessary subs (factor 3) - less agri and waste (factor 2) 	1500 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



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

www.ecocostsvalue.com

USA, and Canada are more recent and accurate see for an explanation [Electricity 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.

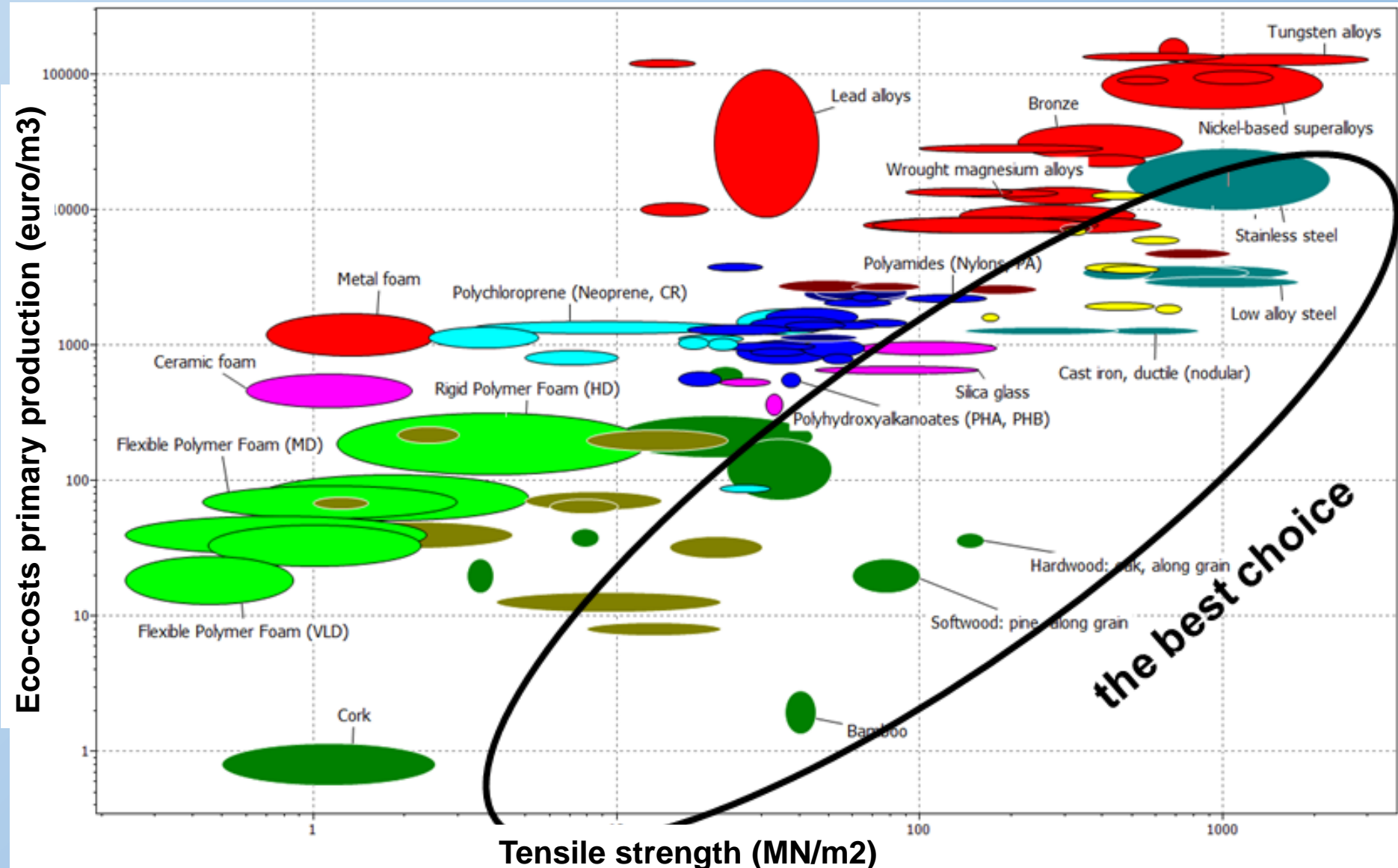
- the **Scope 2 and 3** Ecoinvent dataset with eco-costs ([EI V3-7 with eco-costs.xlsx](#)) is available behind password

Process	Total eco-costs euro
Idemat2023 Silicone rubber (PDMS)	1.77
Materials, 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 fi	0.97
Idemat2023 PE (HDPE, High	1.16
Idemat2023 PE (LDPE, Low	1.17
Idemat2023 PE (LLDPE, Lin	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 (Polyoxymethylen, polyacetaal)	
Idemat2023 PP (Polypropylene)	
Idemat2023 PP GF30	
Idemat2023 PS (EPS, expandable polystyrene)	
Idemat2023 PS (GPPS, general purpose polystyrene)	
Idemat2023 PS (HIPS, high impact polystyrene)	
Idemat2023 PTFE (Teflon, Polytetrafluoroethylene)	
Idemat2023 PTT (Polytrimethylene terephthalate)	0.93
Idemat2023 PVA (wood glue)	1.32
Idemat2023 PVC (Polyvinylchloride emulsion polymerised)	0.81

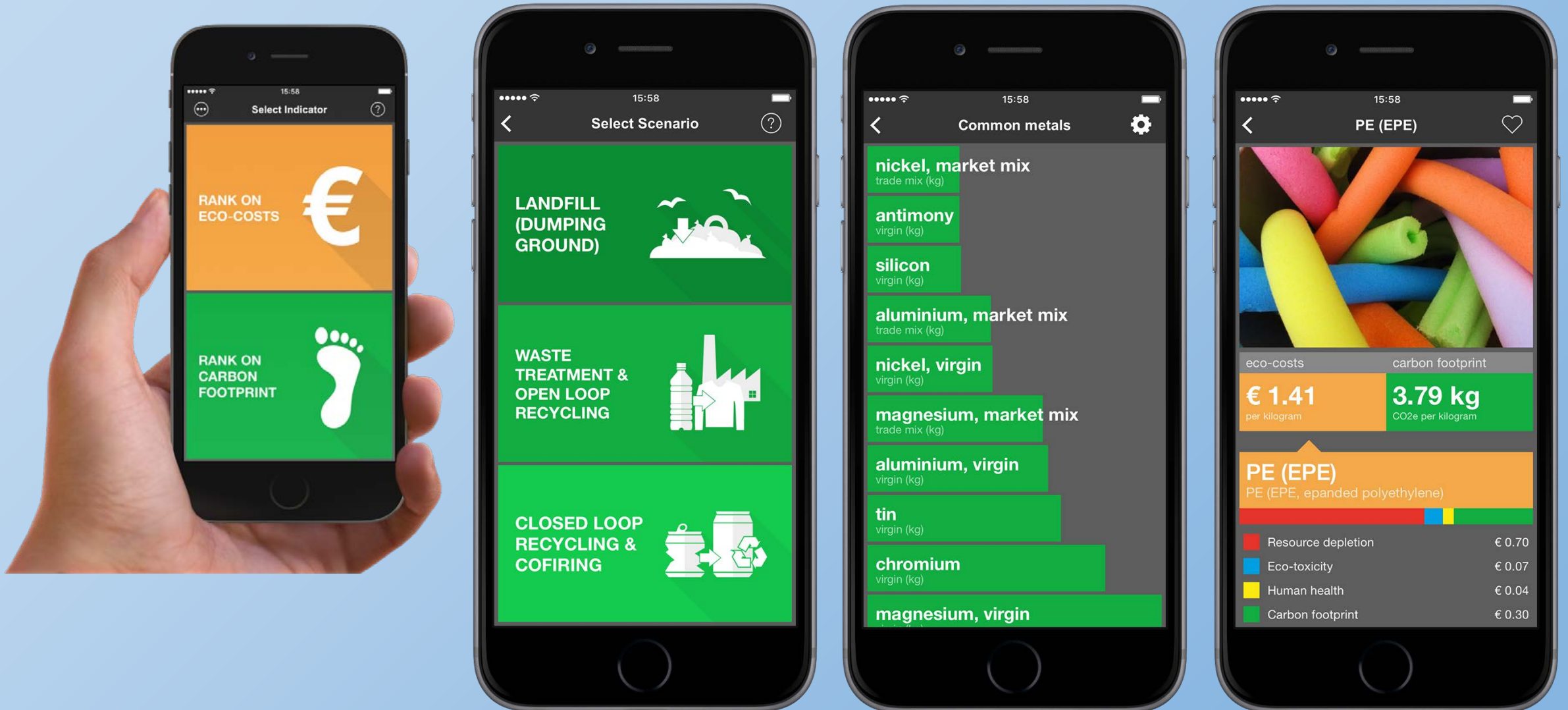
**Carbon Footprint
Cum Energy Demand
ReCiPe
Environmental Footprint**

Direct use of the Idemat data for materials selection

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

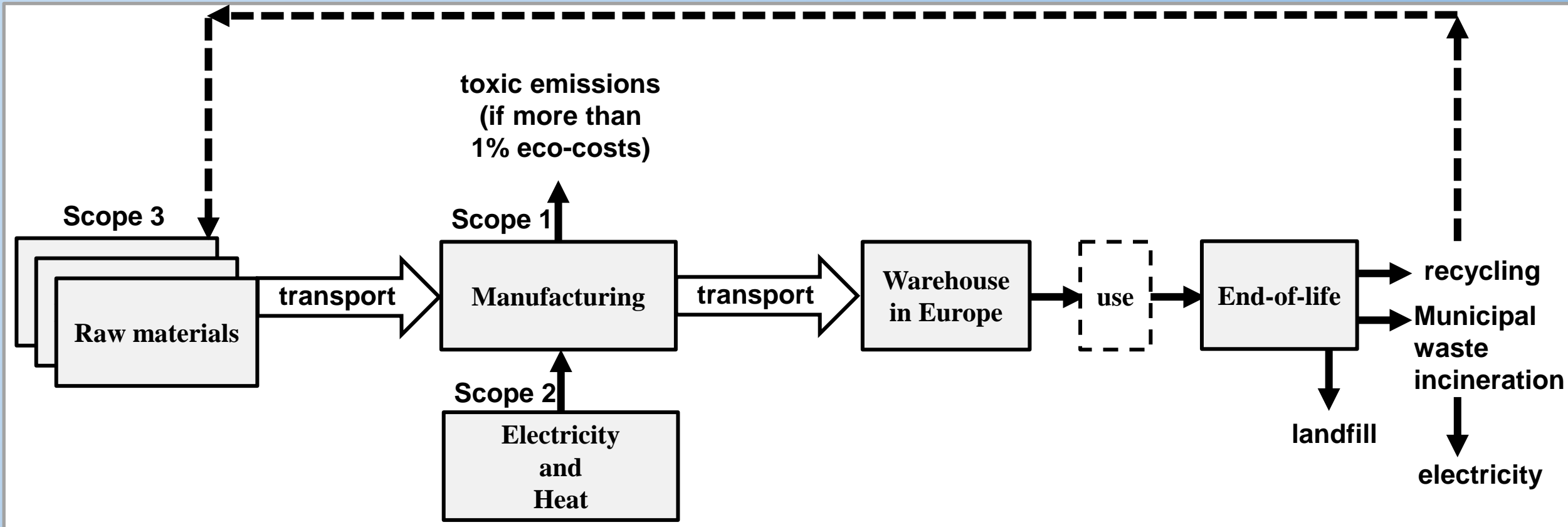


Direct use of the Idemat app for materials selection (to be downloaded from the App store or the Google Play store)



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**

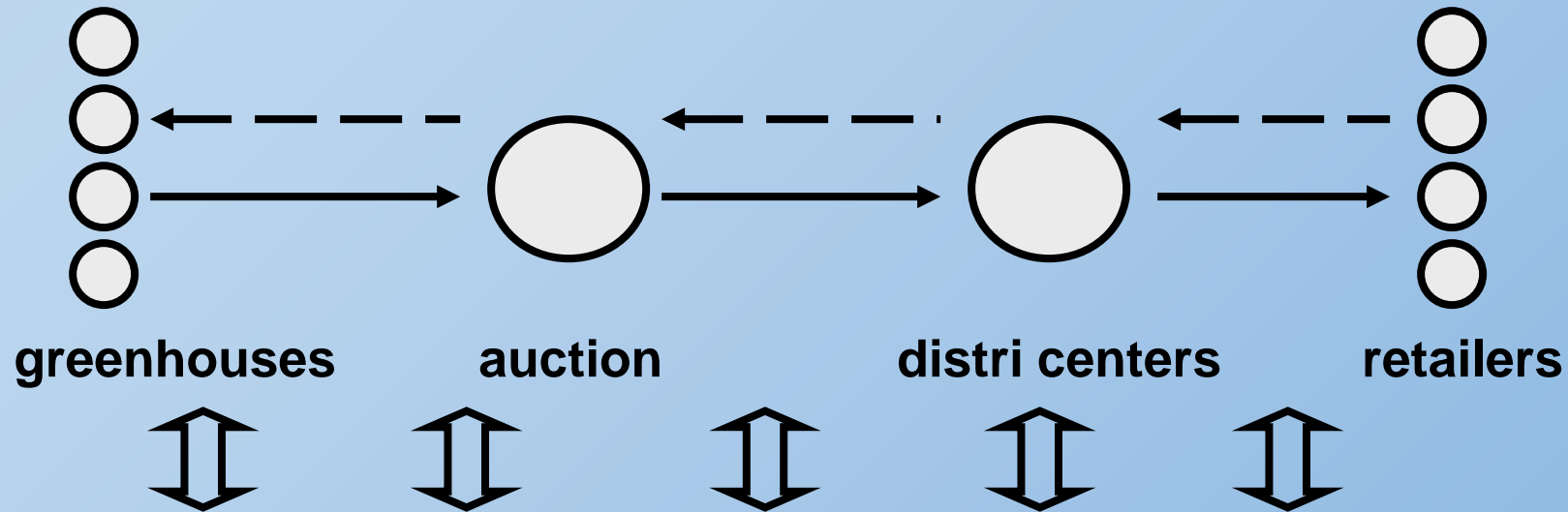
The case: LCA on Transport Packaging
the box and the crate, what is the functional unit?

(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:

<u>Trucks</u>	<u>fork lift trucks</u>	<u>warehouses</u>	<u>transport packaging</u>
- 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)

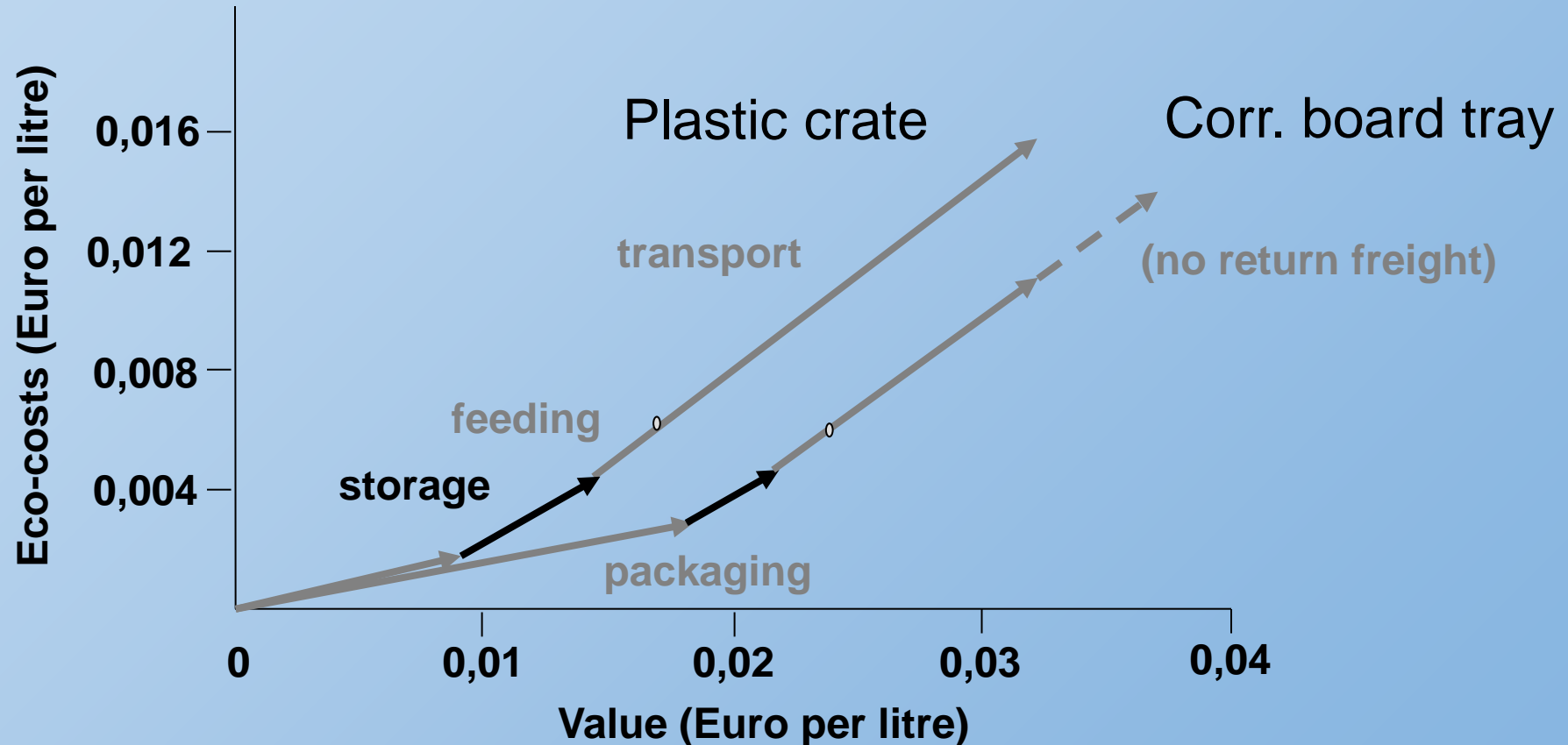
	Corrugated BOXES	Plastic CRATES
Litres per pallet	2670	2196
Litres per truck	69.420	57.096
Eco-costs of:		
- truck+trailer (€/km)	0,31	0,31
(80% diesel incl CO2, 10% rubber, 3% ad blue, 5% exhaust emissions)		
Subtotal (€/km)	0,31	0,31
Km full loaded t+t	$500 + 500 * 0,3 = 650 \text{ km}$	$500 + 500 = 1000 \text{ km}$
Eco-costs (€/trip)	202	310
Eco-costs (€/litre)	0,0029	0,0053

(green numbers are from the database)

The case: Transport of vegetables

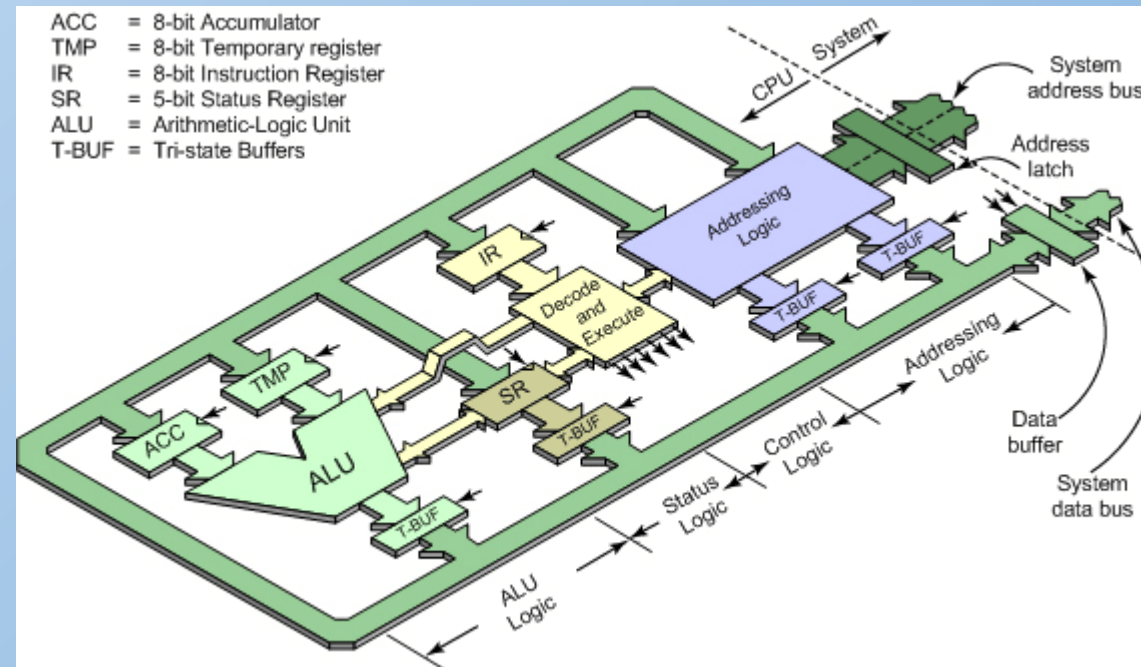
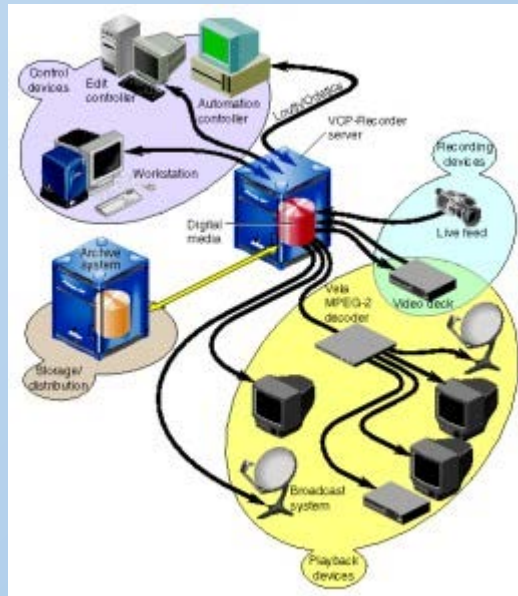
from a Dutch greenhouse to a retail shop in Frankfurt

(FEFCO study, corrugated board tray system with 70% return freight)



Issue 1. the Functional Unit

It is not:



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 system function is:
What? How much? How long? Which quality?

Declared Unit = {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 Drill, Coffee Machine

Examples of Declared Units:

- Wood, Steel, Electricity, Heat, Water
- also: a specific Hand Drill or Coffee Machine

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



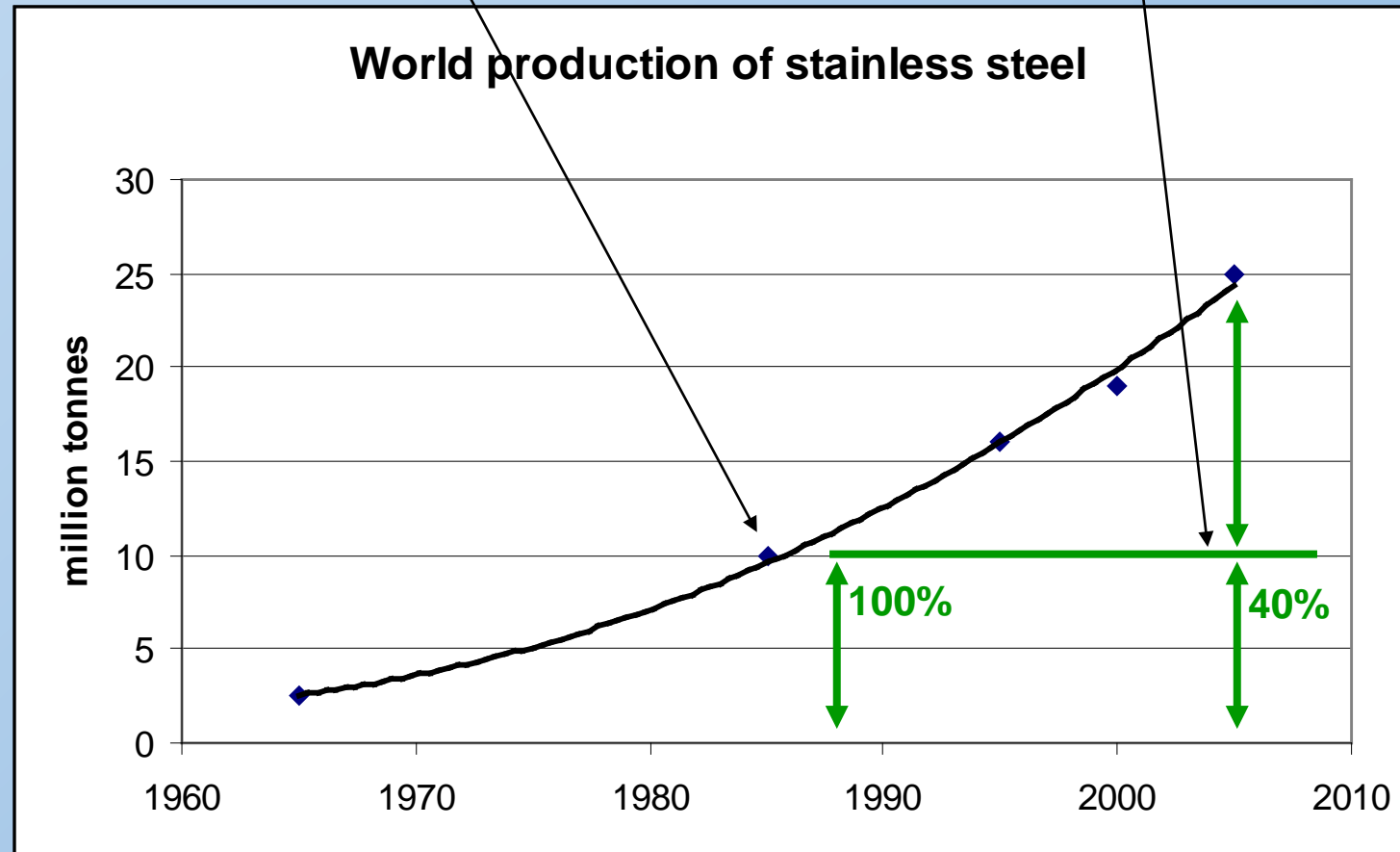
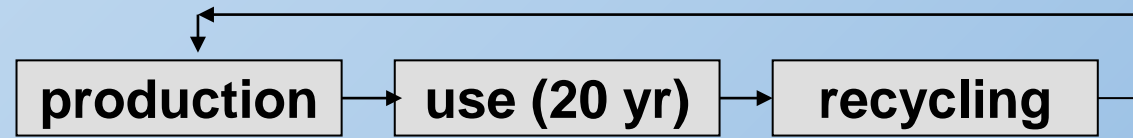
Idemat	freight > 167 kg/m3	freight < 167 kg/m3
Air freight	ton.km	m3.km

For ecoinvent data:

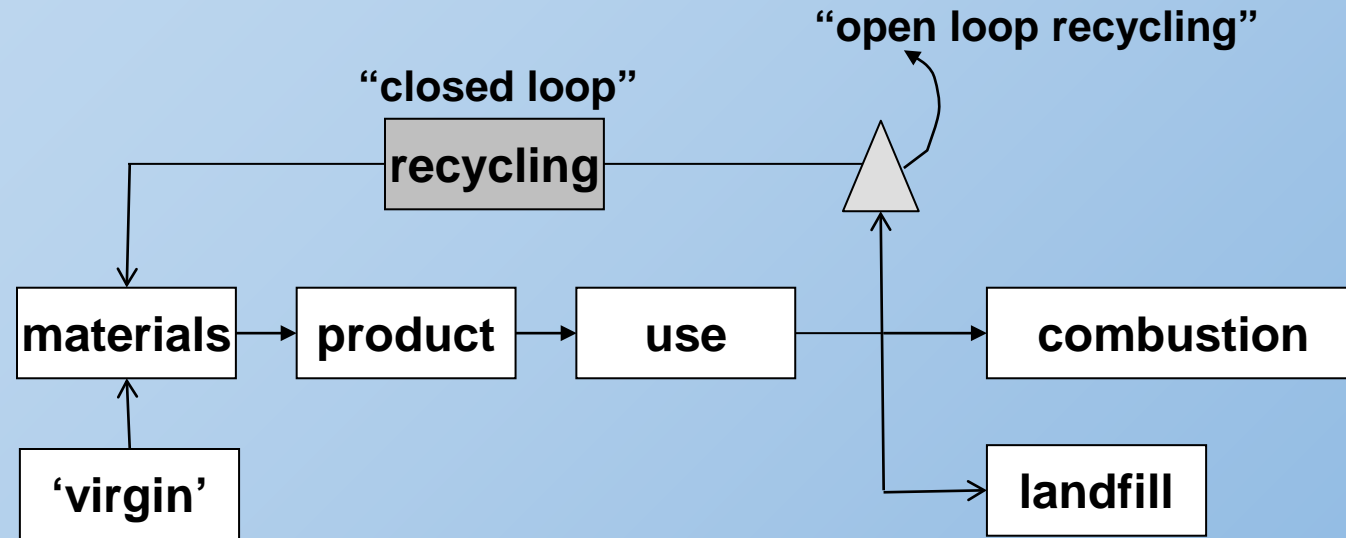
Correction factor of eco-costs per ton.km to eco-costs of light freight:

$$[\text{break-even weight/volume ratio}] / [\text{actual weight/volume ratio}]$$

Issue 3. Recycling percentage Metals ("upcycling open loop")



Issue 4. Recycling Metals and Plastics ("upcycling" and "closed loop")



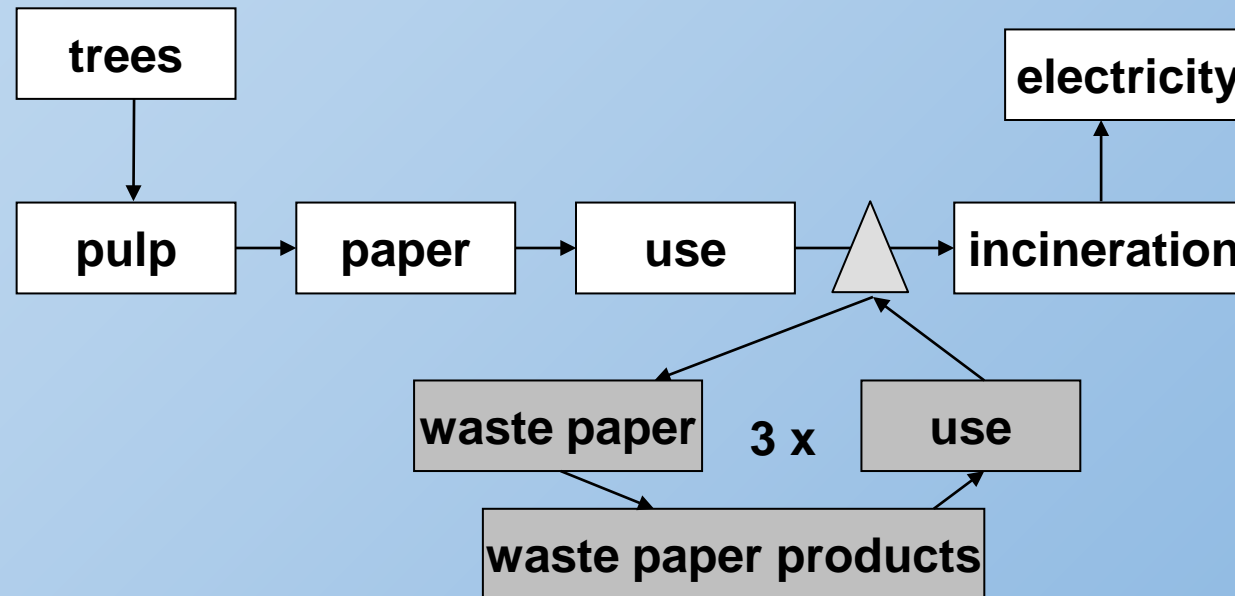
Note 1: In "open loop recycling" the relationship between the old and the new product is not known)

Note 2: the benefit of the recycling goes to the user of the new product (**only closed loop has a "recycling credit"**)

Note 3: in the eco-costs system, the recycled material starts with zero at the sorted waste stockpile (there is no "carry-over" from the old to the new product

Note 4: Preferably work with the right mix at the input side, not with recycling credit

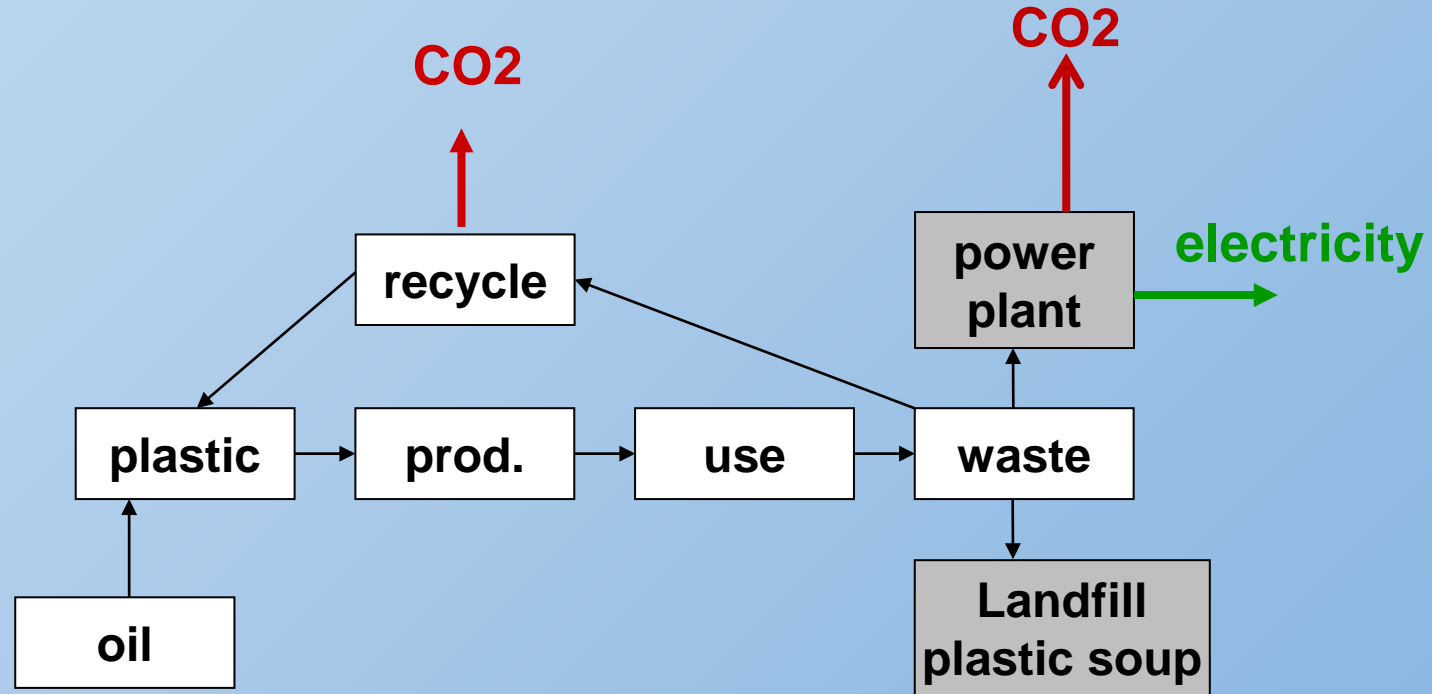
Issue 4. “Downcycling” e.g. Paper



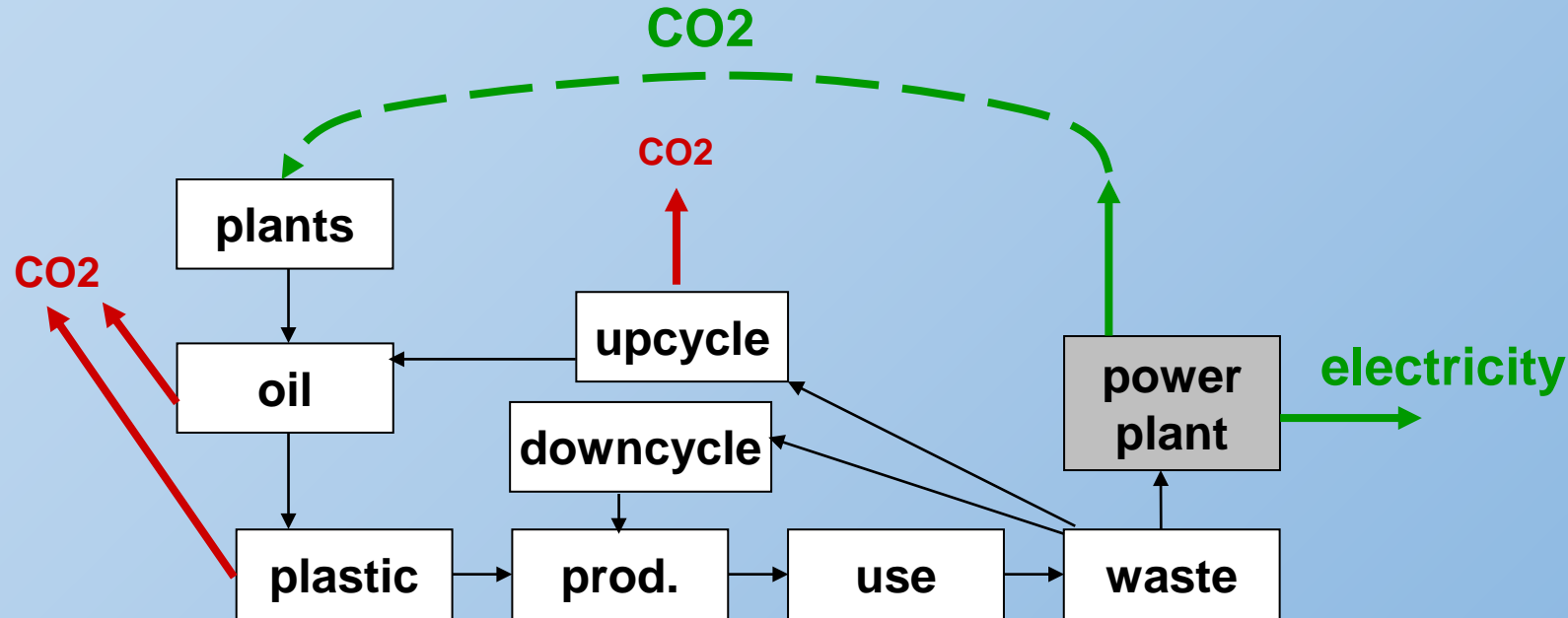
**Note 1: exact recycling percentages are not known
because of imported paper with imported products**

**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 5. Fossil based plastics have no positive end-of-life



Issue 5. Bio-based plastics have a positive end-of-life score in combustion 'with heat recovery'



Note 1: In LCA, biogenic CO₂ (short cycle) is not counted (as it is in the IPCC)

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

Note 3: Sequestration of CO₂ in the product is only counted when the product life is longer than 100 years (that CO₂ has then negative eco-costs)

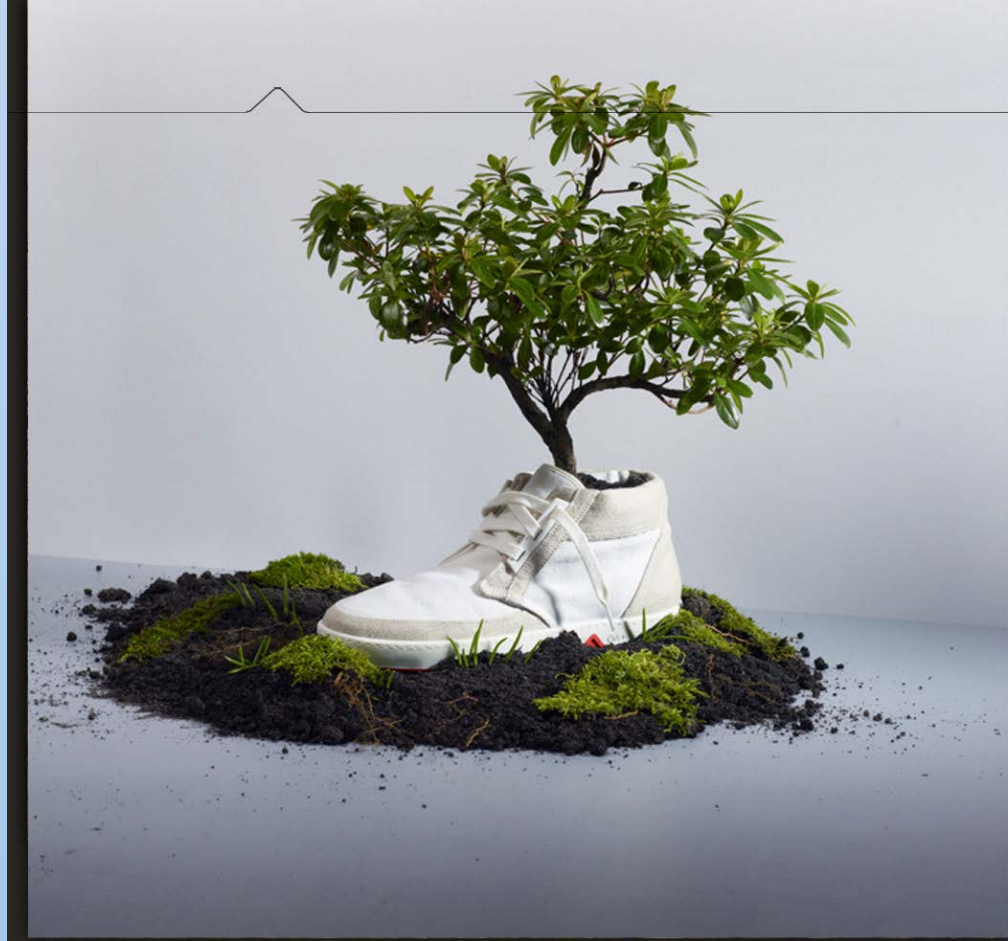
Note 4: In LCA, the CO₂ of wood waste for electricity or heat IS NOT COUNTED

Which statement is true for bio-plastics?

best solution/ solution / worst solution

1. recycling / composting / combustion
2. recycling / combustion / composting
3. composting/ combustion / recycling
4. composting / recycling / combustion
5. combustion / composting / recycling
6. combustion / recycling / composting

Issue 5. Composting scores in marketing better than combustion and recycling. How about the facts?



OAT shoes

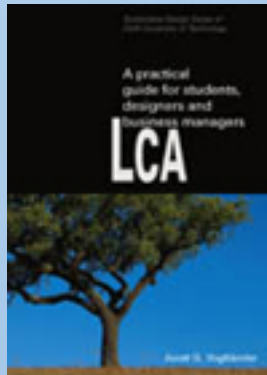
LCA documentation of at the Delft University of Technology

BSc students

from “how to do it”

by

- taking away 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

