# $CO_2$ EMISSION AND BUILDINGS

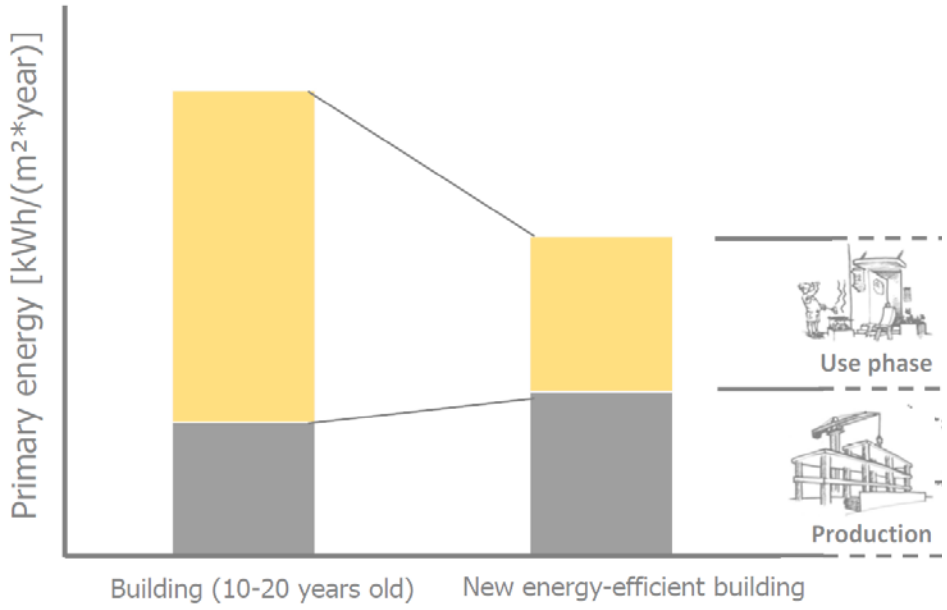
2018-02-02

Christofer Skaar

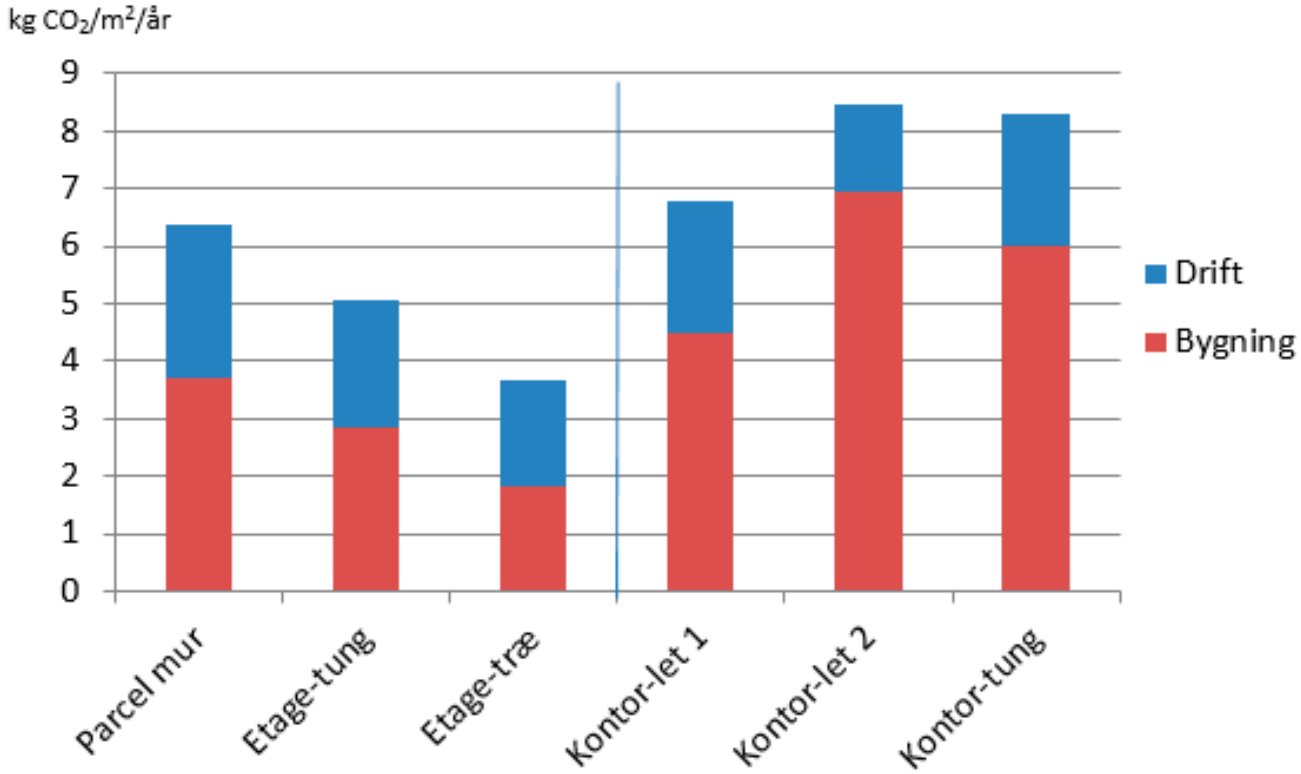
*Senior researcher, SINTEF Building and Infrastructure*

*Adjunct associate professor, NTNU Department of Industrial Economics and Technology Management*

# Buildings: Energy and carbon footprint




Kilde: http://www.eebguide.eu/?p=462




Kilde: SBI (Danish Building Research Institute)



SINTEF

# Agenda

- The big picture
- Environmental management
- Life cycles
- Carbon footprint

# The big picture?

# Why is this important?

I = P x A x T

(Commoner, Ehrlich & Holdren, 1970s)


Keywords: state of the environment, decoupling, factor 4, factor 10, eco-efficiency

SINTEF

# Sustainability

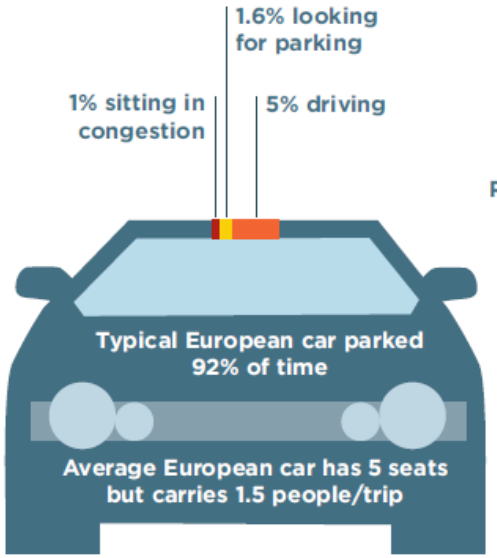



SINTEF

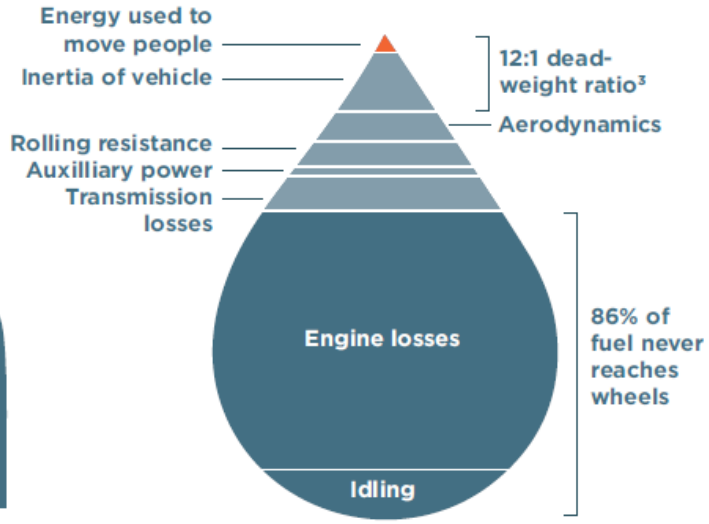
FIGURE 3 **STRUCTURAL WASTE IN THE MOBILITY SYSTEM**

● Productive use

## CAR UTILISATION[1]

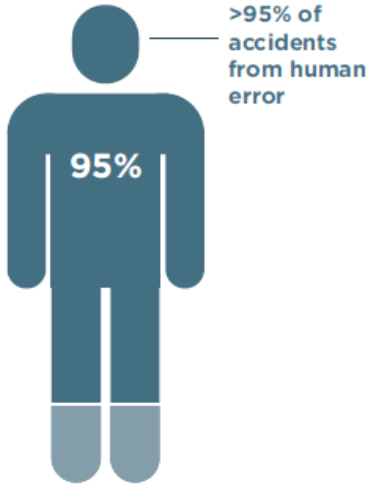



## TANK-TO-WHEEL ENERGY FLOW – PETROL




## DEATHS AND INJURIES/ YEAR ON ROAD

30,000 deaths in accidents and 4X as many disabling injuries[2]

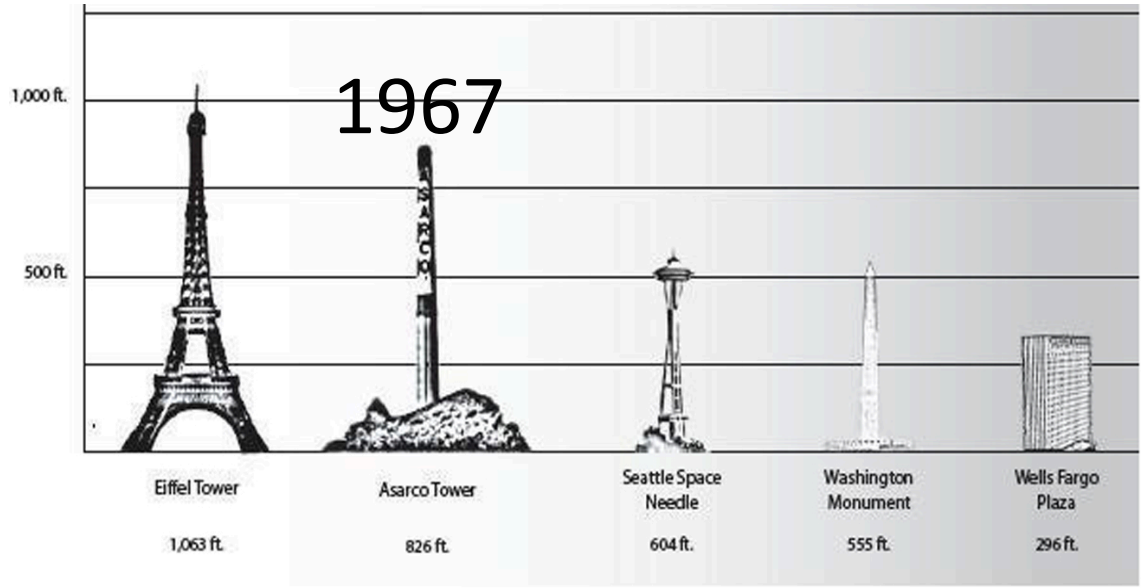



**LAND UTILISATION:** **5%** Road reaches peak throughput only 5% of time and only 10% covered with cars then **50%** 50% of most city land dedicated to streets and roads, parking, service stations, driveways, signals, and traffic signs

MacArthur Foundation / McKinsey (2015)

SINTEF

# How have we dealt with these problems before?




End-of-pipe solutions

1950 1960 1970 1980 1990 2000 2010

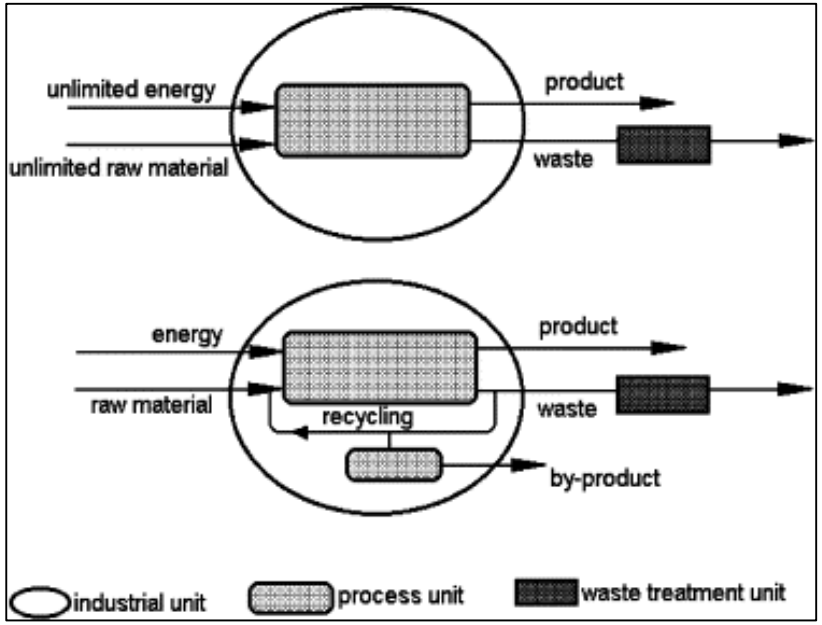
# How have we dealt with these problems before?


Recycling

1950 1960 1970 1980 1990 2000 2010

SINTEF

# How have we dealt with these problems before?

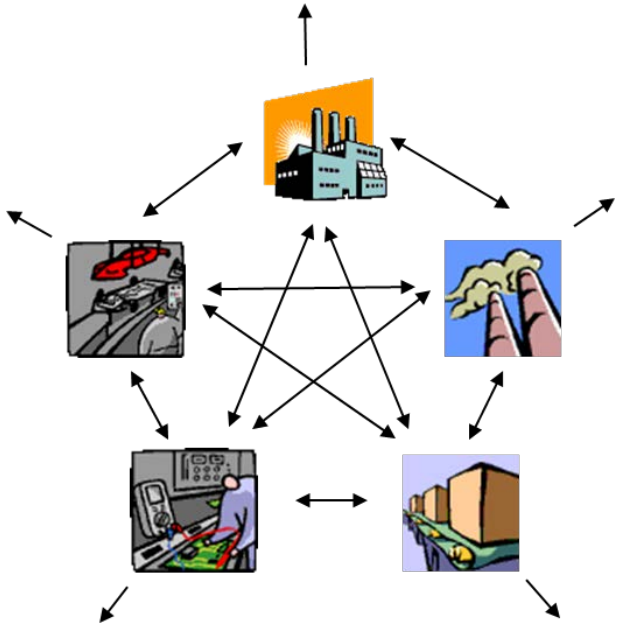


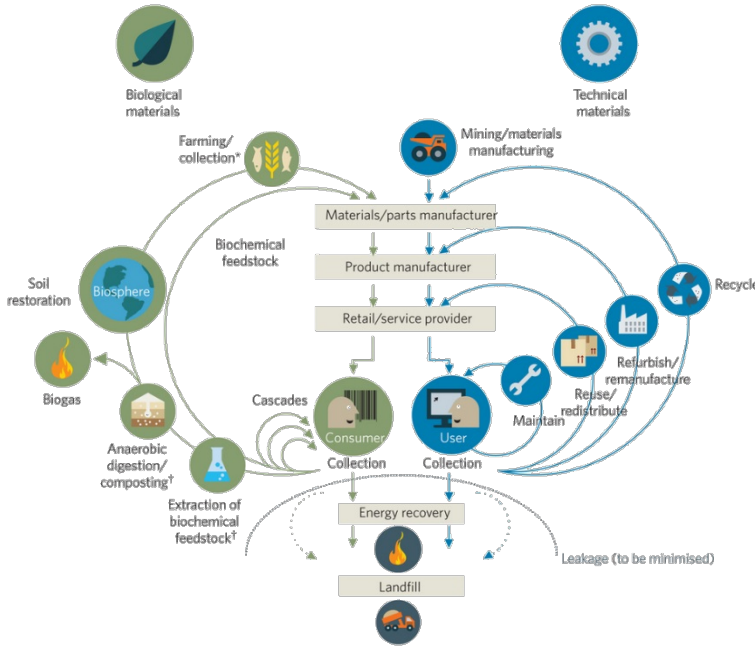

Cleaner production processes

1950 1960 1970 1980 1990 2000 2010

SINTEF

# How have we dealt with these problems before?

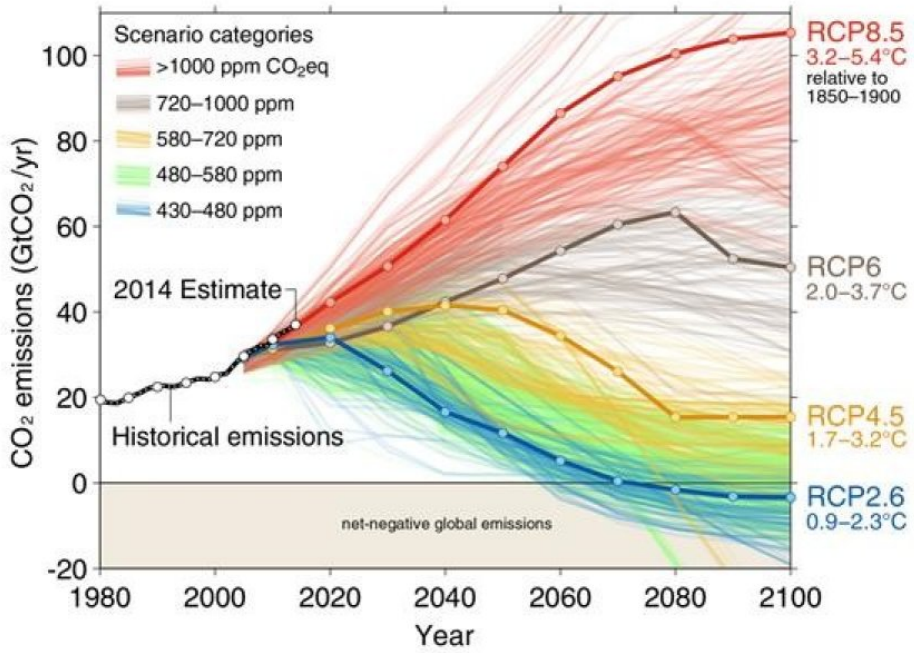





Life cycle perspective *(including circular economy, which is becoming increasingly popular)*

1950 1960 1970 1980 1990 2000 2010

# How will we act in the future?




"Global warming is a total, and very expensive, hoax!"

1950 1960 1970 1980 1990 2000 2010 future

SINTEF

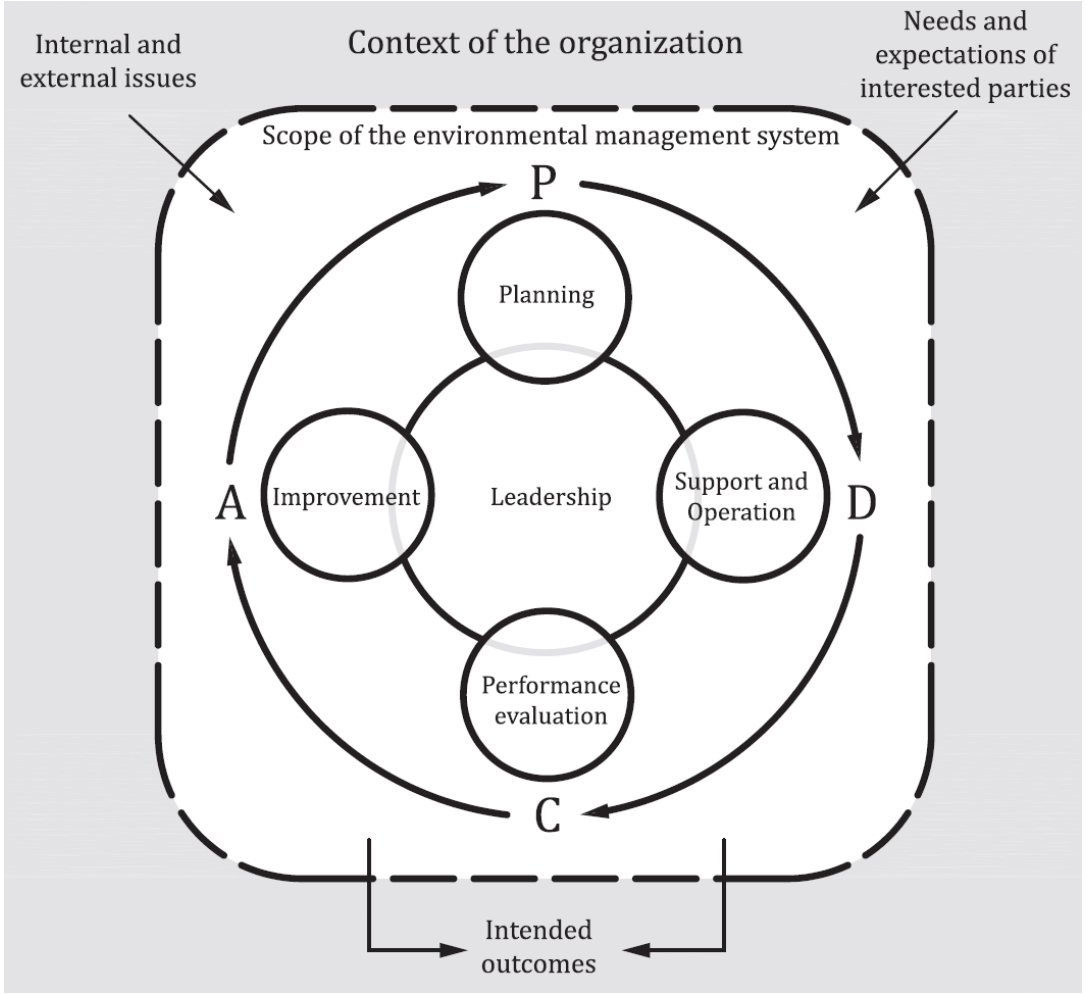
# Environmental management

# Motivations for environmental management

- Customer pressure
- Potential savings
- Legislation
  - Norway: Internal Control Regulations
- Ethics
- Reputation
- Other stakeholders, e.g.
  - Customers
  - Local community
  - NGOs
  - Employees

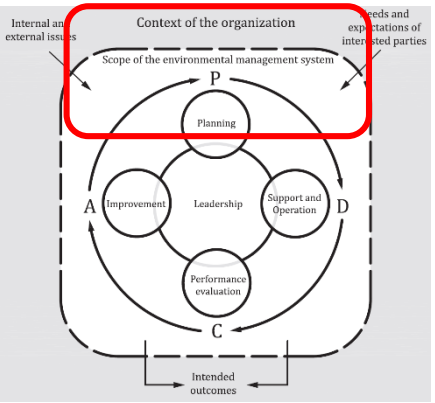

SINTEF

# EMS: Environmental management systems




Source: ISO 14001

PLAN




# Identifying environmental aspects

- Definition (ISO 14001)
  - an **environmental aspect** is an element of an **organization's** activities or products or services that can interact with the **environment**
- Cause-and-effect: Activity → impact
- Elements, examples:
  - discharges, emissions, consumption, reuse, generation of noise
- Positive or negative impact on the environment
- Scope
  - Local, regional, global
  - Upstream and downstream (‘that it can influnce’)
  - Normal and abnormal operating conditions

SINTEF

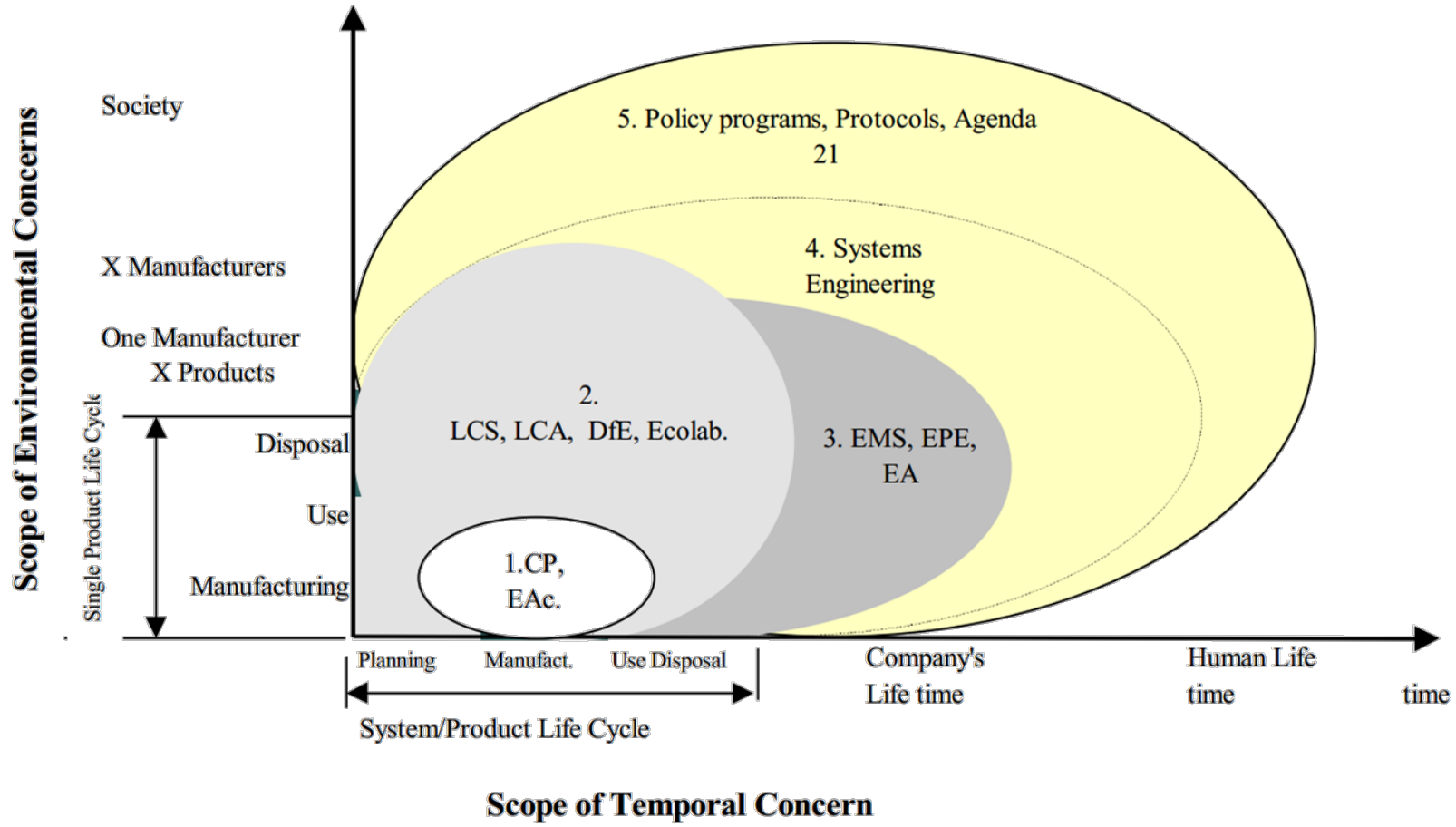
# Tools and methods

(a few examples)

- Process related
  - Cleaner Production (CP)
  - Environmental accounting (EAc)
- Product related
  - Life Cycle Assessment (LCA)
  - Material, Energy and Toxicity analysis (MET)
  - Product labels/declarations
  - Design for X (DfX, x = environment, recyclability, re-use, etc.)
- Management related
  - Environmental management
  - Environmental auditing
  - Environmental performance evaulation

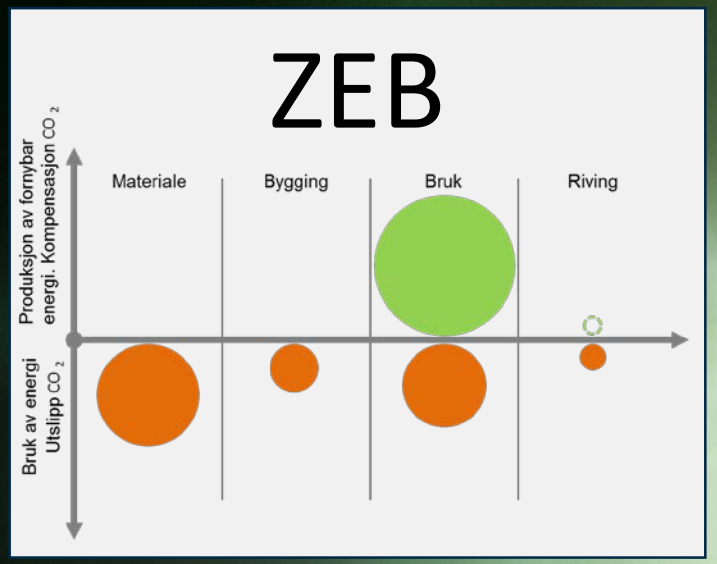
SINTEF

# Tools and methods




Fet (2000)

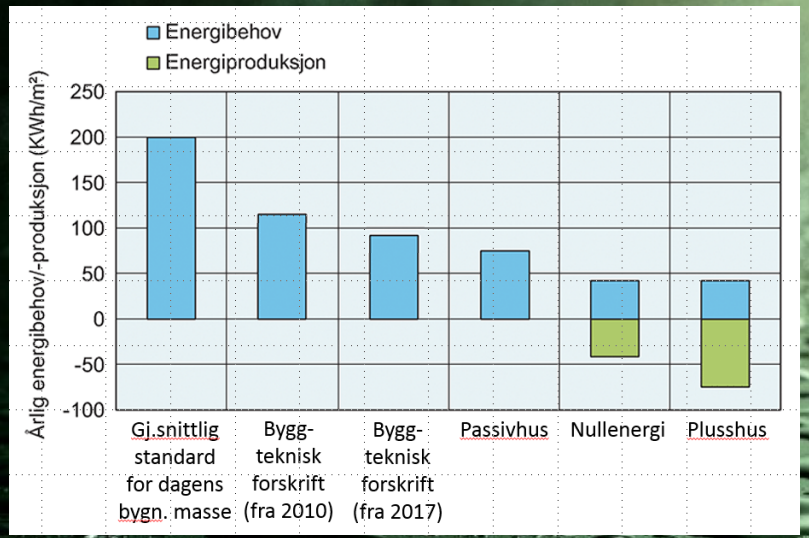
# ZEB




BREEAM® NOR

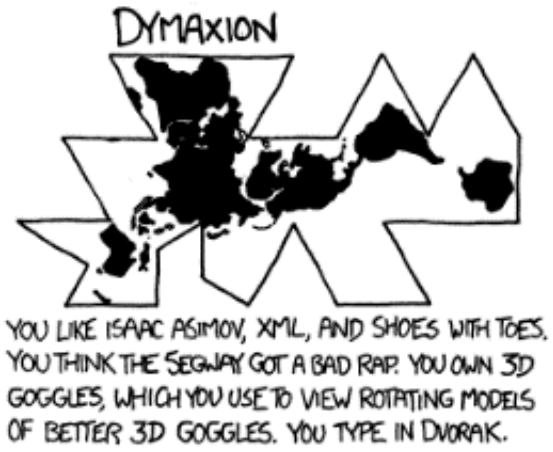
Goal?

# Method



# Beware:
# Mapping the landscape







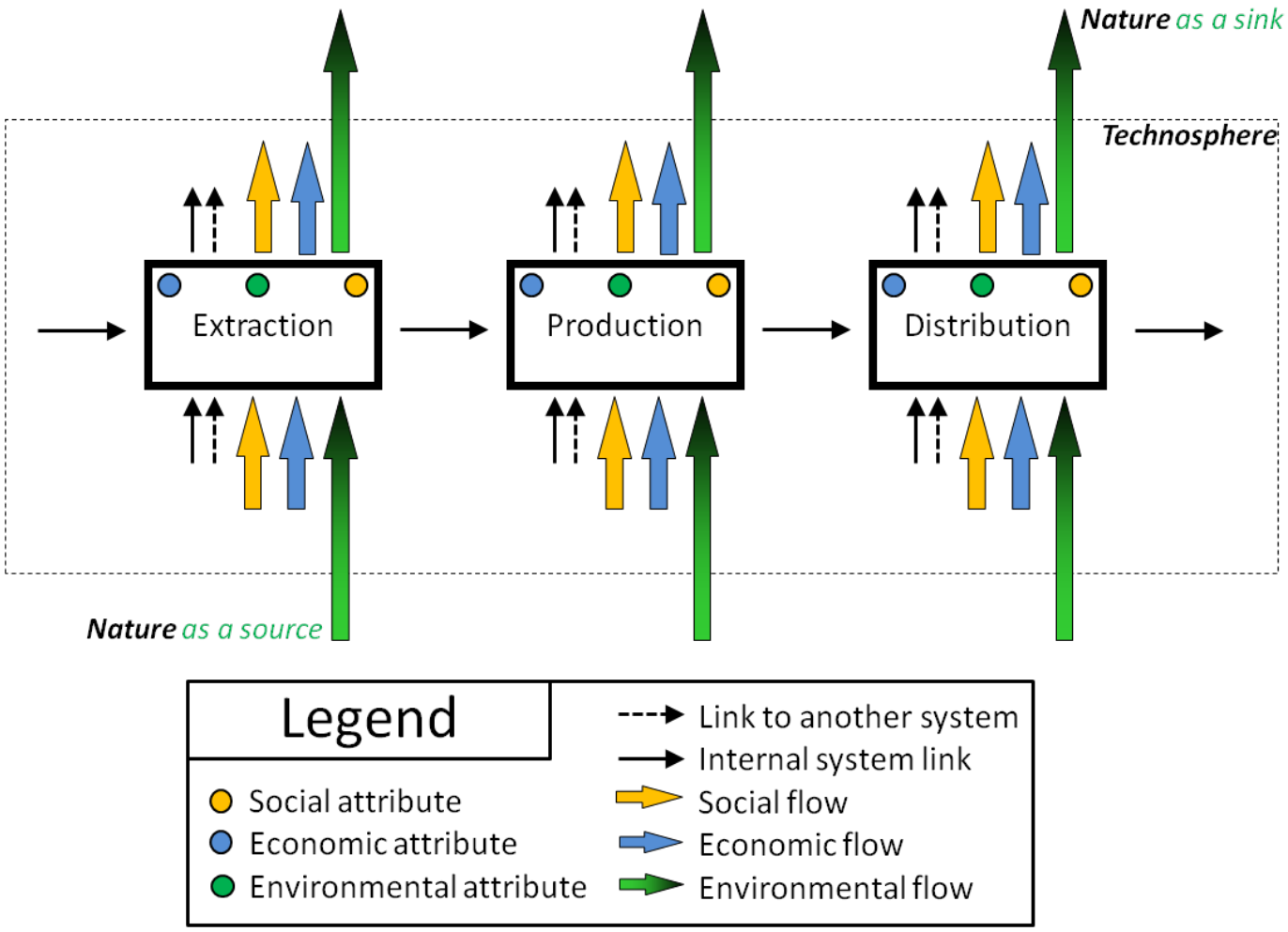


xkcd.com

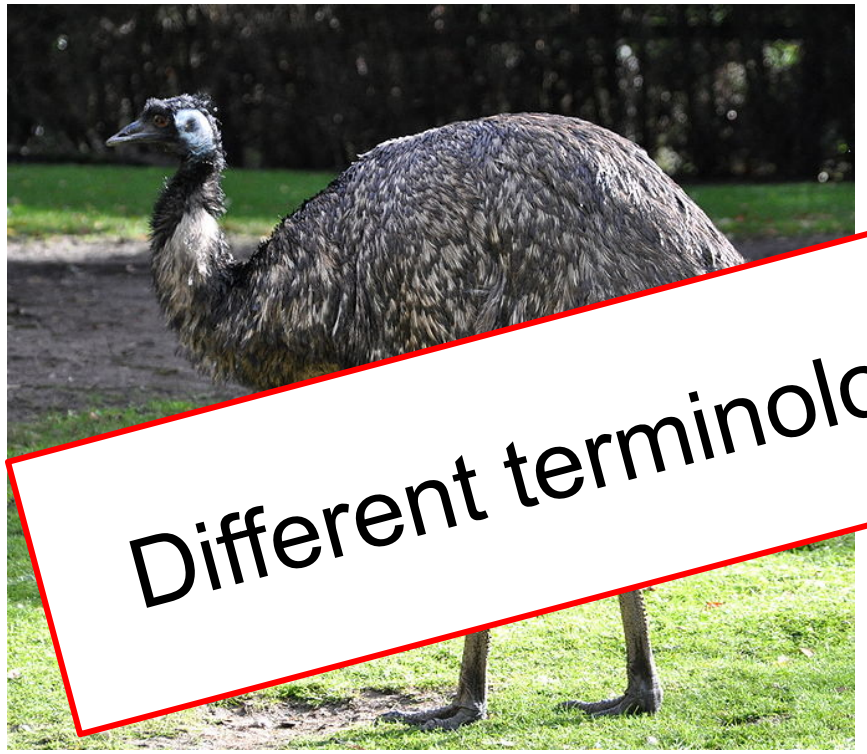
*Box (1976): All models are wrong, but some are useful*

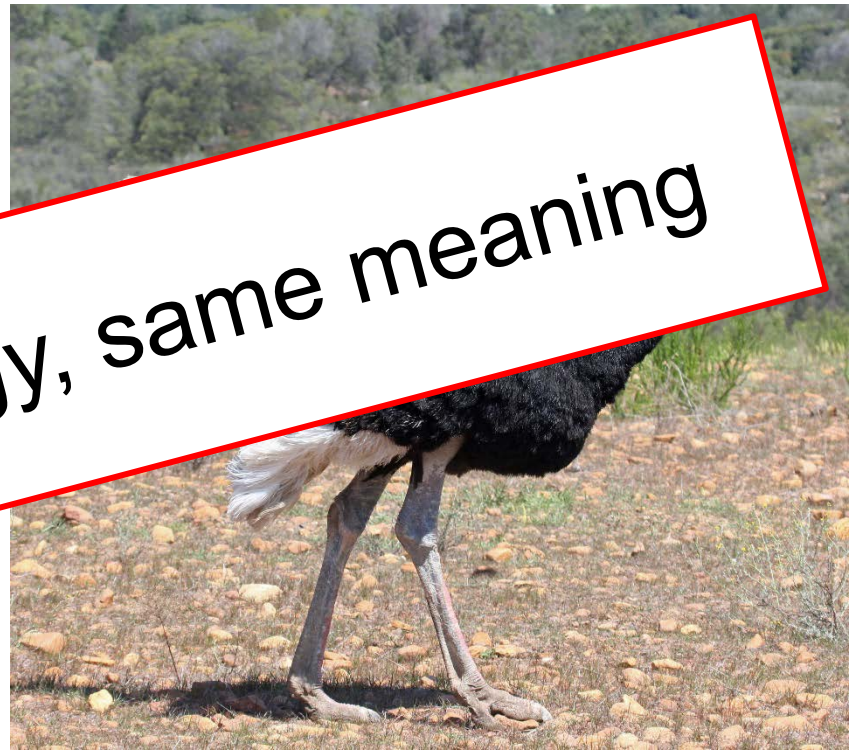
# Life cycles

# Life cycle perspective



# Life cycle





Different terminology, same meaning

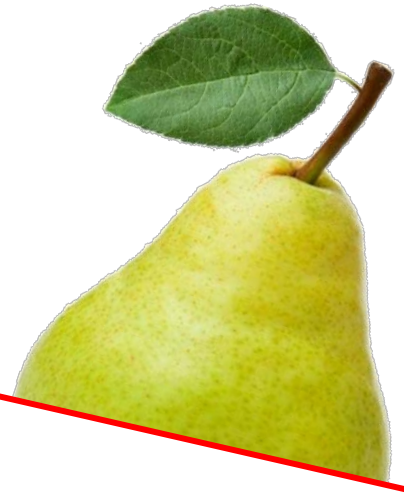
# Life cycle: Similar approaches

- Life cycle
  - “consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal” (ISO 14040:2006)
- Value chain
  - “the full range of activities which are required to bring a product or service from conception, through the different phases of production (involving a combination of physical transformation and the input of various producer services), delivery to final consumers, and final disposal after use” (Kaplinsky & Morris 2001)
- Supply chain
  - “network of connected and interdependent organisations mutually and co-operatively working together to control, manage and improve the flow of materials and information from suppliers to end users” (Aitken, in Christopher 2005)
- Commodity chains
  - “network of labor and production processes whose end result is a finished commodity” (Hopkins & Wallerstein, 1986)
- Value stream
  - “specific activities required to design, order, and provide a specific product, from concept to launch, order to delivery, and raw materials into the hands of the customer.” (Womack & Jones, 1996)

SINTEF

# [**la**jf **saj**kəl]


# [oh **pair**]



**Oh, pear!**

Same terminology, different meaning

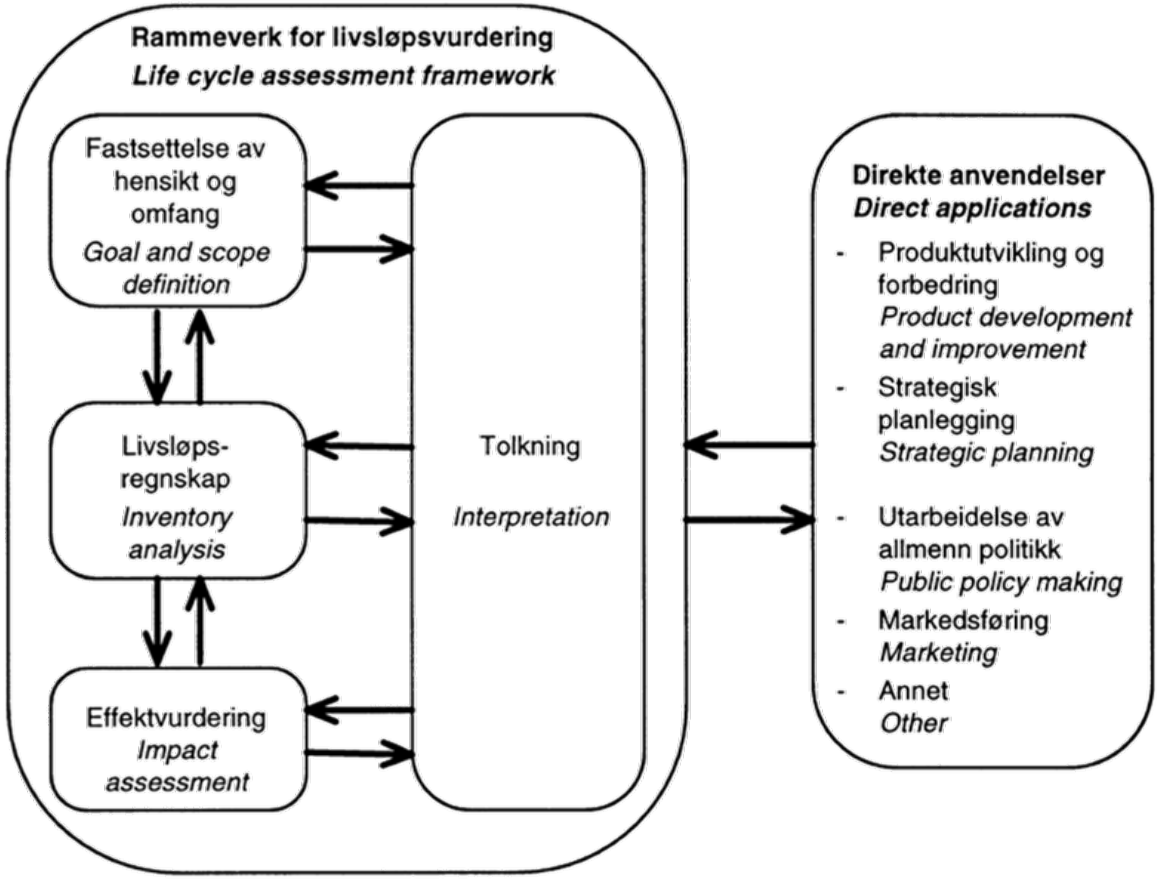
An **au pair** is a domestic assistant from a foreign country working for, and living as part of, a host family. Typically, **au pairs** take on a share of the family's responsibility for childcare as well as some housework, and receive a monetary allowance for personal use. en.wikipedia.org/wiki/**Au_pair**

SINTEF

# Which life cycle?

- Project life cycle
- Product life cycle
- Software development life cycle
- Building life cycle
- System life cycle
- etc.

# ISO 14040 and ISO 14044: Life Cycle Assessment (LCA)




**Figur 1 – Faser i en LCA**
*Figure 1 – Phases of an LCA*

ISO 14040

# Why use LCA?

- LCA calculates the total environmental impact throughout the value chain
- Identifies problem shifting
  - Example A: A factory stops surface coating of its products. The factory emissions are lowered, but the lifetime of the product is halved. The total environmental impact increases.
  - Example B: Shifting from gasoline to electric cars. Total impact increases.
  - Example C: Shifting from gasoline to electric cars. Total impact decreases.

# Why use LCA?

- Product improvement
  - Shows where the environmental loads occur (is the problem the choice of materials, processes, energy carriers, suppliers?)
  - Value chain development
- Comparison of products
  - Product development
  - Competitive advantage
- Advertisement / product information
  - Environmental Product Declaration (EPD)
  - Environmental labelling (the Swan, EU Flower, etc.)

# Why use LCA?

- Example results:
  - Paper or ceramic:
    200 paper cups = 1 ceramic cup
  - Disposable diapers vs cloth diapers
    - In UK: little difference
    - In Norway: cloth diapers slightly better
  - … but these results depend on how and where you use the products.
  - **Exercise:** Paper versus ceramic.
    What are the main processes in the two life cycle?
    How can the use phase influence the results? (significant parameters)

SINTEF

# Why use LCA?

- As a producer, you are responsible for your products
- From previous lecture:
  - The Product Control Act (1976)
  - Environmental Information Act (2004)
  - Ecodesign directive
- Also
  - Moral responsibility
  - Customer demand
  - Risk management

SINTEF

# What can be analysed?

- LCA is used to analyse
  - Products
  - Services
  - Functions
- The concept of function is central
  - Products and services are analysed be looking at which function it fulfils

  *Example: The function of a chair is to provide seating for X years.*

# Linking to EMS: Standards and the life cycle perspective

**Analysis and documentation**

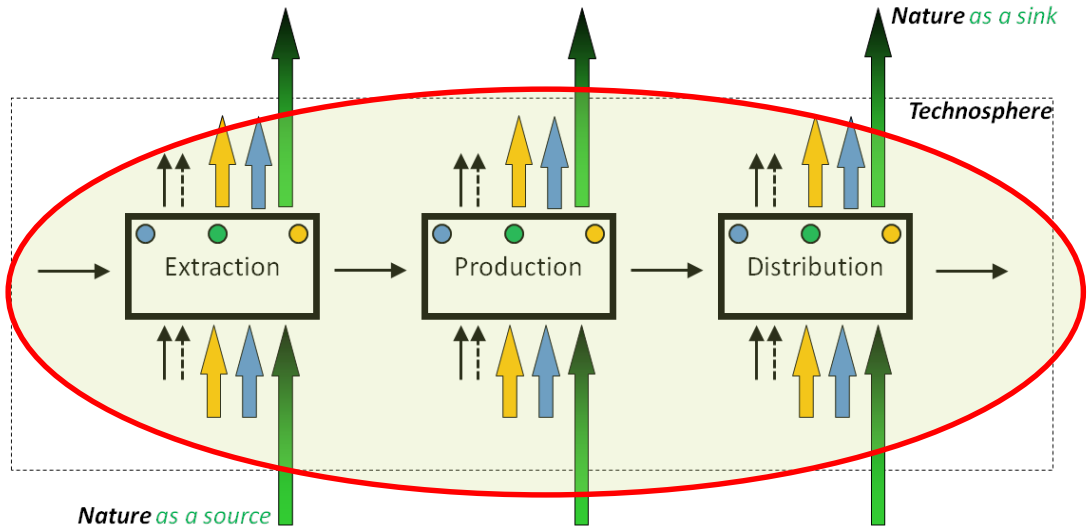
ISO 14040 LCA, principles

ISO 14044 LCA, requirements

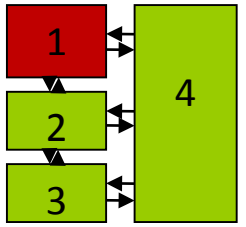
ISO 14045 Eco-efficiency, products
ISO 14064 Climate footprint, org.
ISO 14067 Climate footprint, prod.

**Communication**

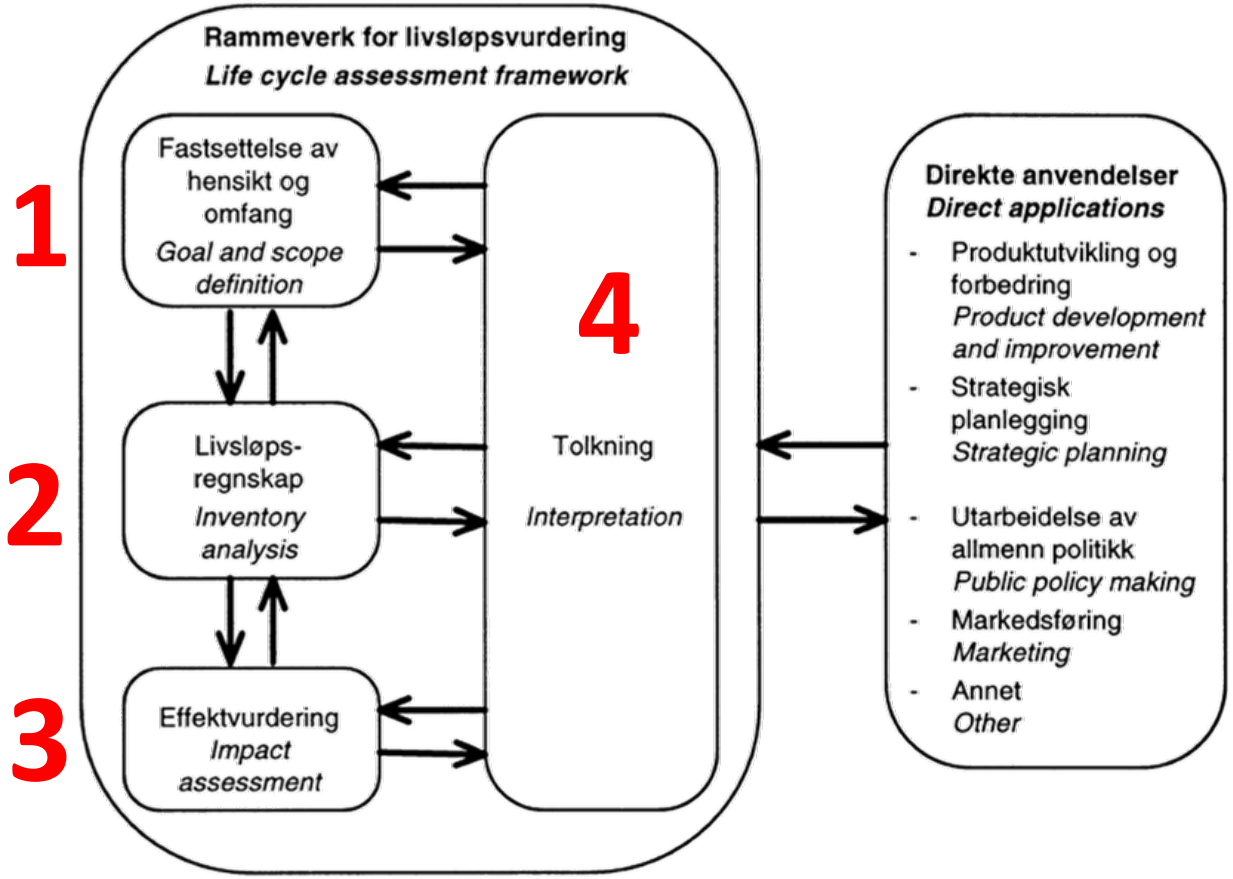
ISO 14020 Env. labelling, principles
ISO 14021 Self-declared claims
ISO 14024 Environmental labelling
ISO 14025 Environmental declarations
ISO 14064 Climate footprint, org.
ISO 14067 Climate footprint, prod.




SINTEF




# LCA methodology

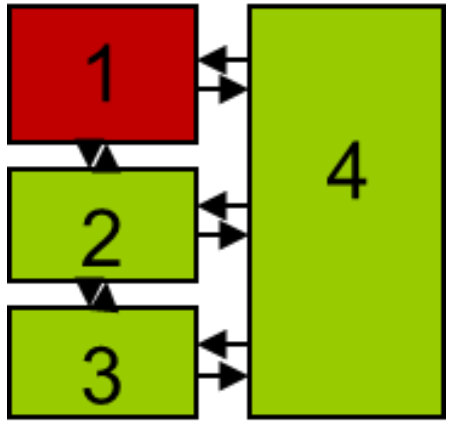



**Figur 1 – Faser i en LCA**
*Figure 1 – Phases of an LCA*

ISO 14040

SINTEF

# 1. Goal and scope



# FUNCTION?

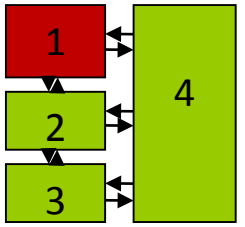
Depends on context:
Who, what, how, where, when, how long, how good?

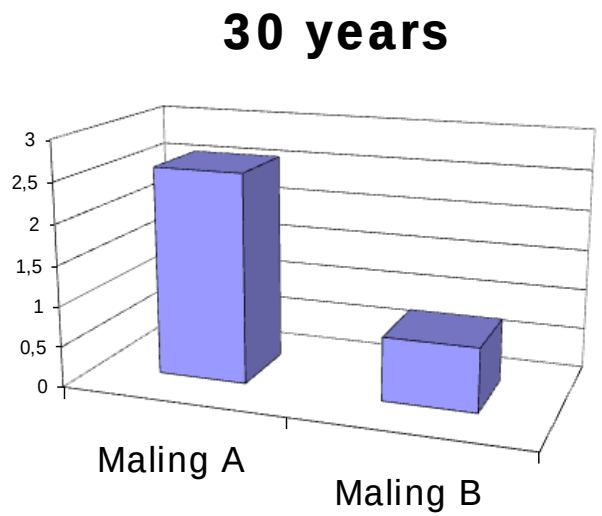
# Example

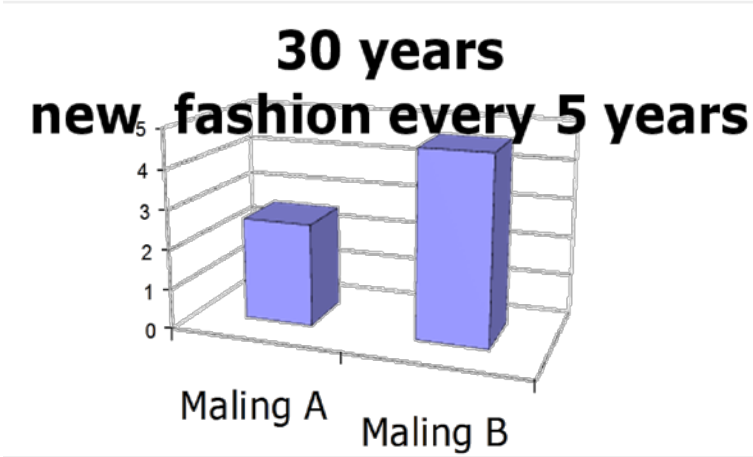
Paint A
Lifetime: 5 years
Coverage: 6,5 sqm/liter
Env. load: 0,43 Ecopoints

Paint B
Lifetime: 30 years
Coverage: 6,5 sqm/liter
Env. load: 0,78 Ecopoints

Function:
Preserve wall for 30 years

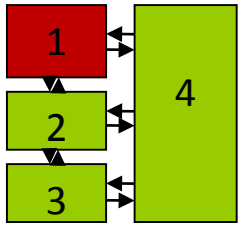


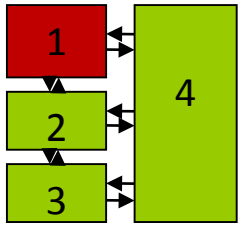

SINTEF

# Functional unit (FU)




Purpose?

- Example, paint: ***The function*** is preserving the wall. The ***functional unit*** is not ‘a can of paint’ or ‘1 liter of paint’, but rather ‘conserving 10 m2 wall for 10 years’.
- Three dimensions
  - Quantity (‘how much?’)
  - Quality (‘how good?’)
  - Duration (‘how long?’)




# Functional unit and goal of study

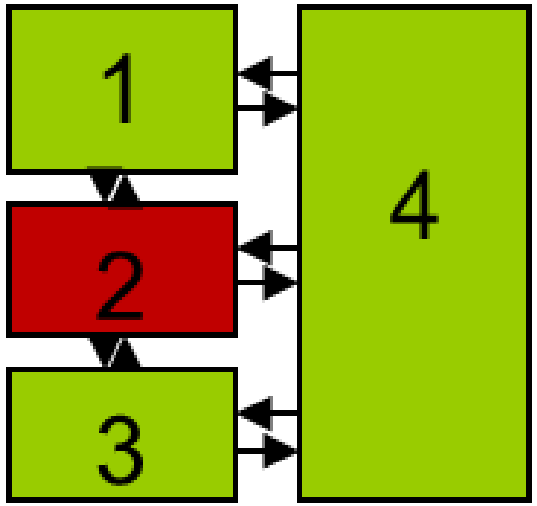
- Stakeholders often do not know the goal
- Find out what they really want!
- Formulate the research question
- Functions: what is the purpose of the product system?
- Reference flows (also relevant for analysing alternative systems)

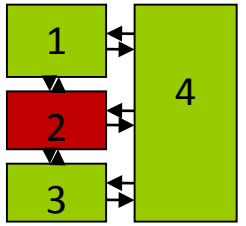
- **Exercise:** Client approaches you and say they want to compare incandescent lighting to LED lighting in a life cycle perspective

- Questions? Function(s)? Implications for data modelling and inventory structuring?

SINTEF

# 2. Life Cycle Inventory (LCI)






# Process inventory

## Flows of material or energy

Iron ore, bauxite, chlorine, wood, air, peat, gold, grain, heat, etc.

Energy

Material resources

Process chemicals

Prosess

Emissions to air

$CO_2$
$SO_x$
$NO_x$
$CH_4$
benzen
HF
heat
dust
etc.

Products

Bi-products

Emissions to water

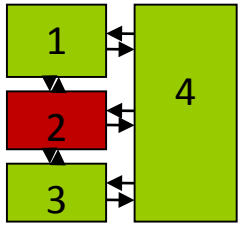
Emissions to land

Wastes

nitrogen, arsenic, hydrogen chlorie, pesticides, heat, carbon dioxide, particles, oil, process water, etc.

Source: Baumann & Tillman

SINTEF




# Process inventory

## Flows of material or energy

Iron ore, bauxite, chlorine, wood, air, peat, gold, grain, heat, etc.

Energy

Material resources

Process chemicals

Prosess

Emissions to air

$CO_2$
$SO_x$
$NO_x$
$CH_4$
benzen
HF
heat
dust
etc.

Products

Bi-products

Emissions to water

Emissions to land

Wastes

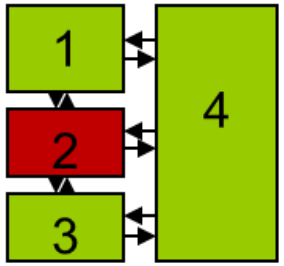
nitrogen, arsenic, hydrogen chlorie, pesticides, heat, carbon dioxide, particles, oil, process water, etc.

Elementary flows are flows from nature to man-made systems, and vice versa

Source: Baumann & Tillman

SINTEF

# Life Cycle Inventory




$SO_x$
$NO_x$
$CH_4$
benzene
HF
dust
etc.

Iron ore, copper ore, sand, bauxite, silicon, chlorine, kaolin, wood, water, air, peat, corn, gold, stone, soil, etc.

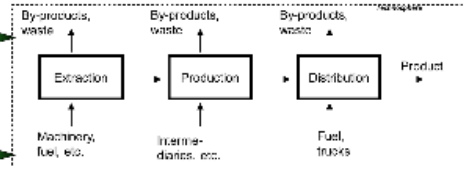
Σ

Energy

Material resources

Σ

Technosphere




Σ

Emissions to air

Σ

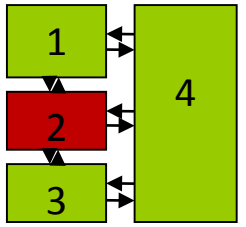
Emissions to water

Emissions to soil

Σ

nitrogen, arsenic, hydrogen chloride, pesticides, oil, process water, hydrogen chloride, etc.

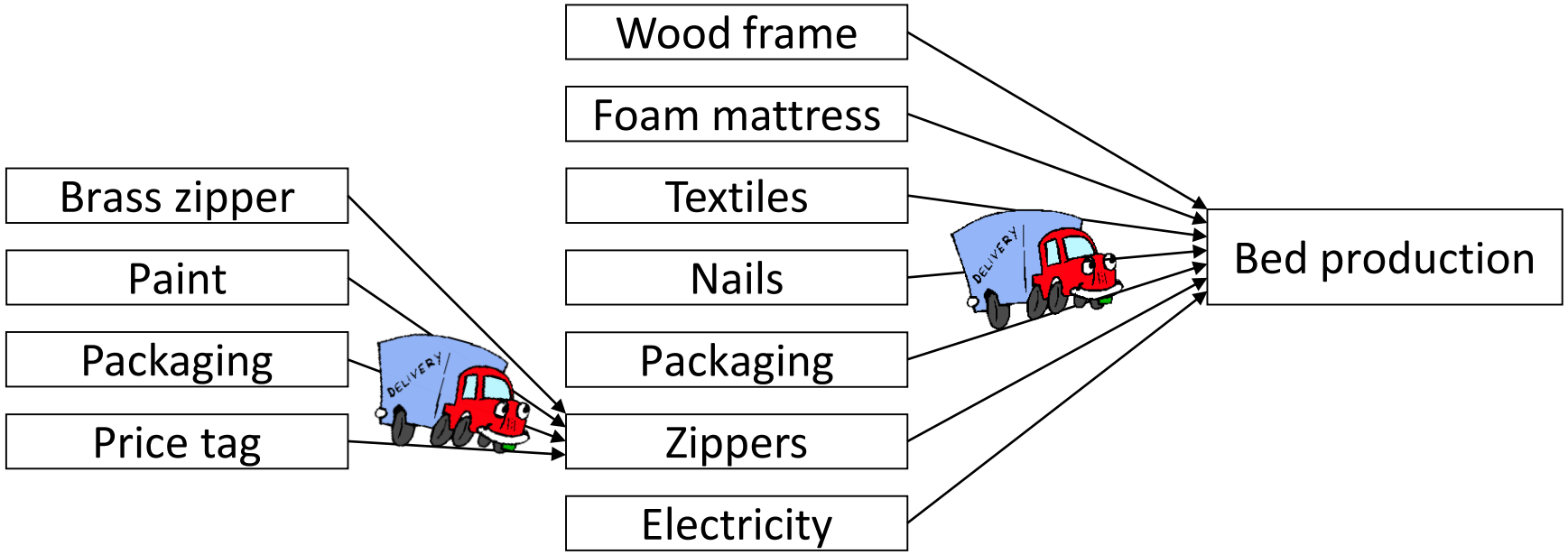
Calculate the elementary inputs and outputs for all processes we have in our system.




# 2. Inventory
# Flow diagram

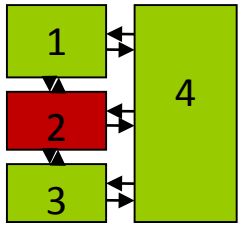
The criteria for system boundaries are defined in the goal and scope phase. A simple criterion can be:

- Include all significant processes



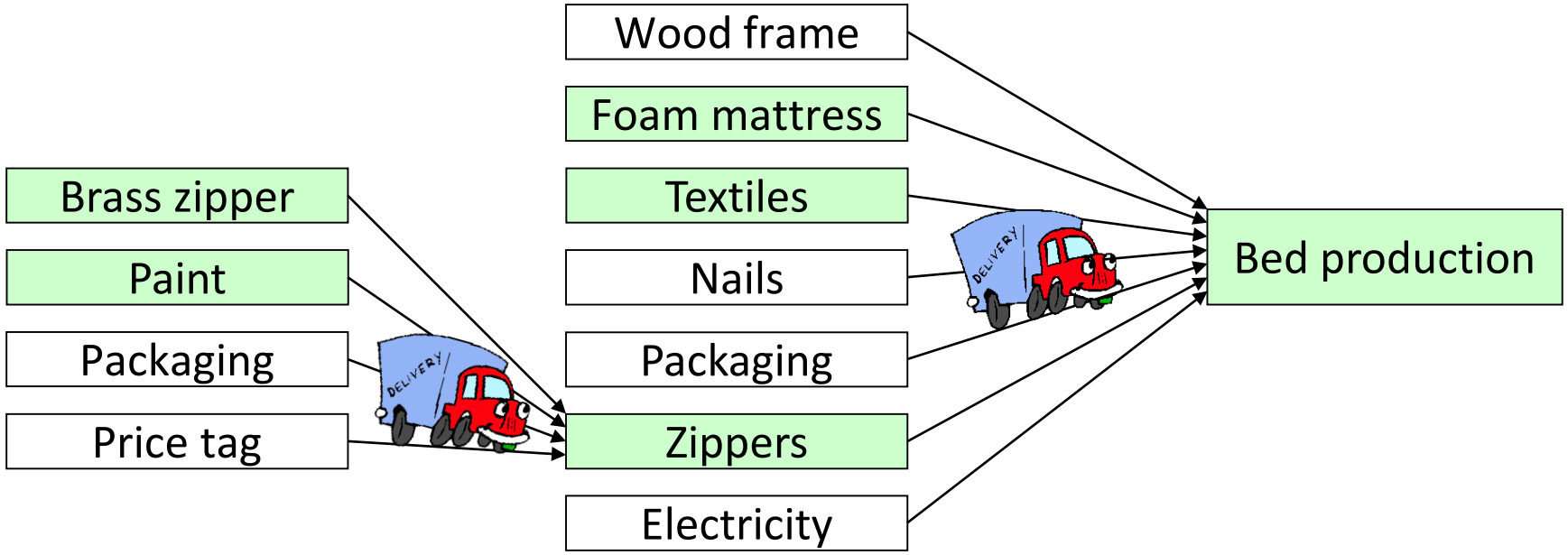

Which processes are significant for our study?

SINTEF




# 2. Inventory *(complexity)*
# Foreground and background system

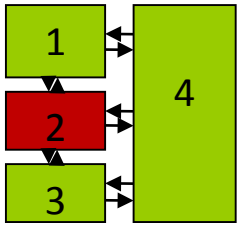
- Foreground: specific data gathered by you
- Background: generic data from databases

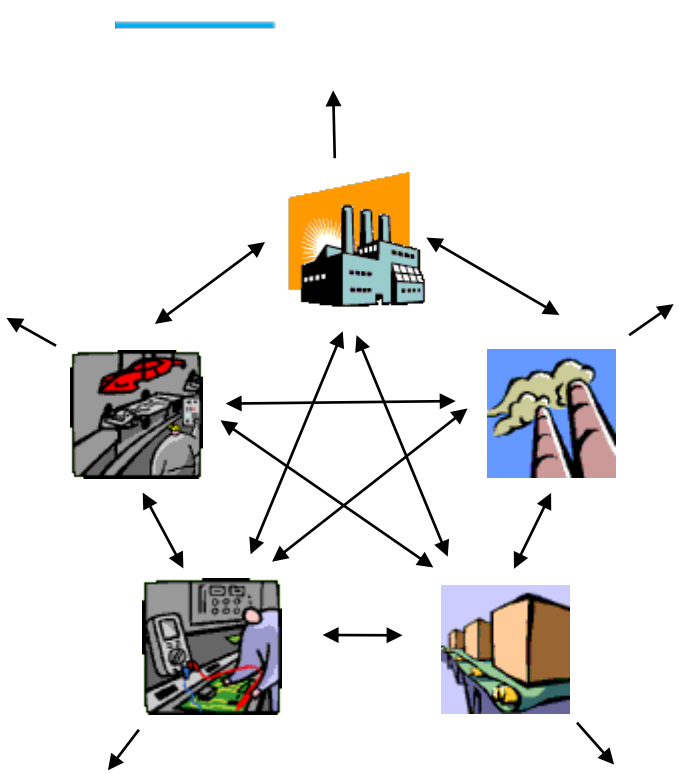


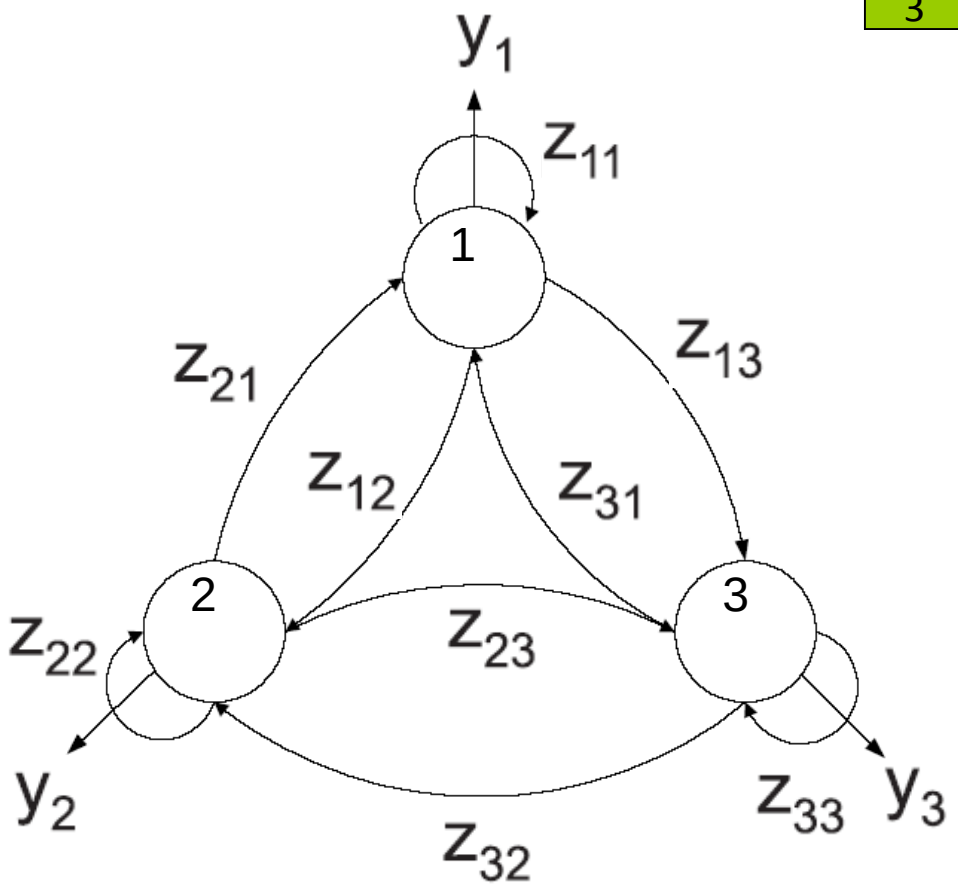

Example: here our goal is to improve the mattress in a bed,
we therefore decide to use generic/average data for the rest of the bed

SINTEF

# Calculating the flow (open Leontief model)



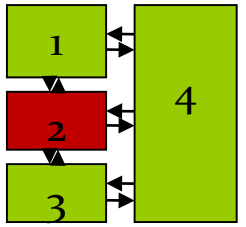






*"...the system of economic interrelationships may be represented as a long path describing a wide circle and ending up again at its starting point. All along the way, it branches off into numerous smaller paths, some of which interweave in all manner of combinations..."* Leontief (1928).

Source: Solli and Strømman (2005)

SINTEF




# 2. Inventory: Complexity

$$x = (I - A)^{-1} y$$

The Leontief inverse

$$\begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_{pro} \end{pmatrix} = \left[ \begin{pmatrix} 1 & 0 & \dots & 0 \\ 0 & 1 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & 1 \end{pmatrix} - \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1pro} \\ a_{21} & a_{22} & \dots & a_{2pro} \\ \vdots & \vdots & \ddots & \vdots \\ a_{pro1} & a_{pro2} & \dots & a_{propro} \end{pmatrix} \right]^{-1} \begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_{pro} \end{pmatrix}$$

$$e = Fx = F(I - A)^{-1} y$$

$$\begin{pmatrix} e_1 \\ e_2 \\ e_3 \\ \vdots \\ e_{str} \end{pmatrix} = \begin{pmatrix} f_{11} & f_{12} & \dots & f_{1pro} \\ f_{21} & f_{22} & \dots & f_{2pro} \\ f_{31} & f_{32} & \dots & f_{3pro} \\ \vdots & \dots & \ddots & \vdots \\ f_{str1} & f_{str2} & \dots & f_{strpro} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_{pro} \end{pmatrix}$$

$$d = Ce = CF(I - A)^{-1} y$$

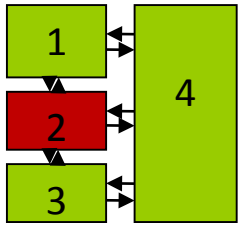
$$\begin{pmatrix} d_1 \\ \vdots \\ d_2 \end{pmatrix} = \begin{pmatrix} c_{11} & c_{12} & c_{13} & \dots & c_{1str} \\ \vdots & \dots & \vdots & \ddots & \vdots \\ c_{imp1} & c_{imp2} & c_{imp3} & \dots & c_{impstr} \end{pmatrix} \begin{pmatrix} e_1 \\ e_2 \\ e_3 \\ \vdots \\ e_{str} \end{pmatrix}$$

y = demand vector
A = process dependency matrix
x = output vector
F = elementary flow matrix
e = elementary flow vector
C = characterisation matrix
d = impact vector

Source: Solli and Strømman (2005)

SINTEF

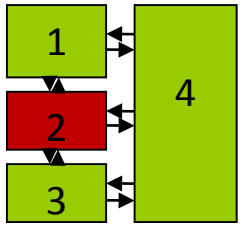
# System boundaries



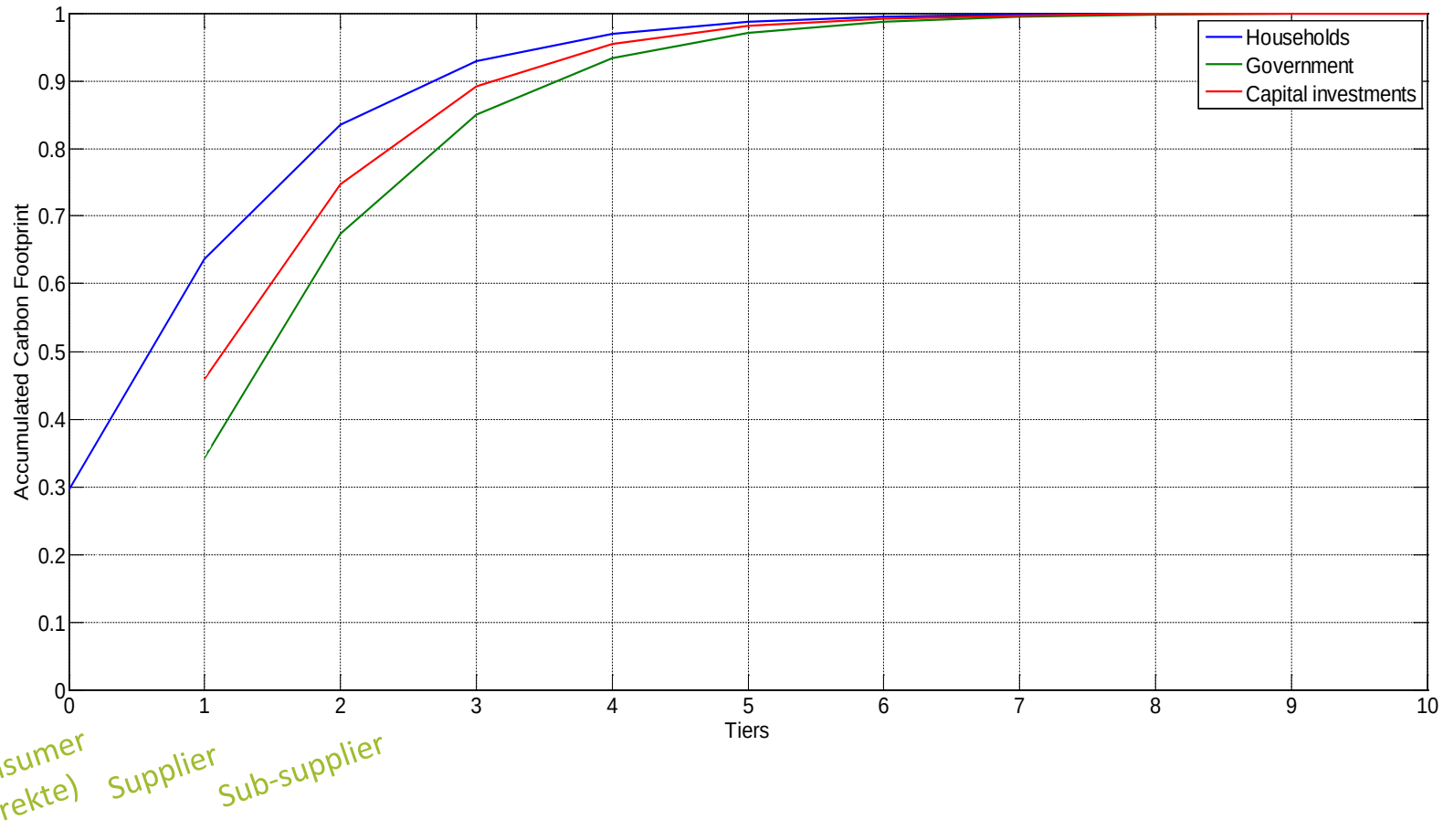

- What should we include and what should we exclude?

- Criteria for boundary selection = cut-off criteria
  - Preferably environment: ”all significant impacts included”
  - Sometimes mass
  - Or energy
  - Or cost
  - Often some idea (qualified guess? literature data? preliminary calculations?) about the significance of a process is used in the end to determine whether or not to include.
  - Many small left out contributions may add up to significant cut-offs. Eg. IO vs process LCA

# System boundary selection



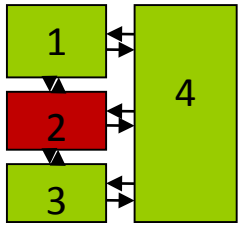

*Upstream in the value chain*




Source: H. Larsen

SINTEF

# System boundary selection




**Life Cycle Emission Distributions** 925

*Upstream in the value chain*

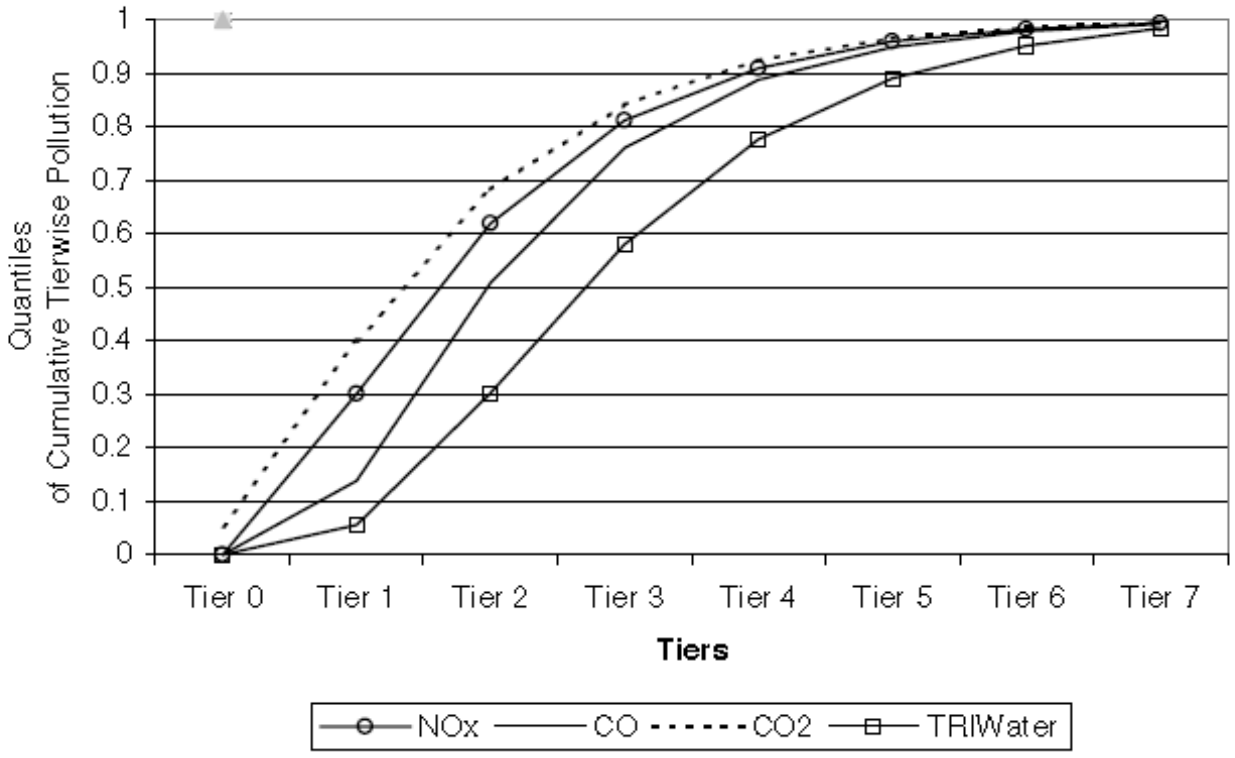
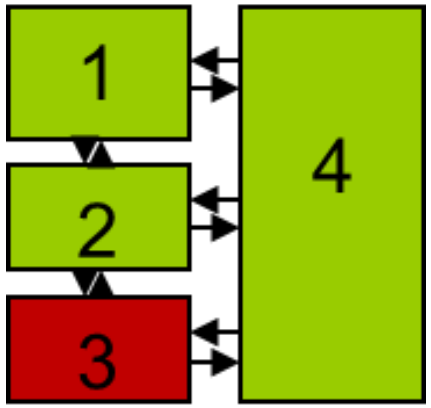


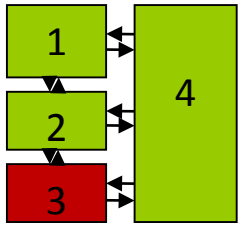

**Fig. 4.** 25th percentiles for upstream convergence, by pollutant type; convergence is slower than indicated for 25% of the commodities in the U.S. economy.

Norris 2002

SINTEF

# 3. Life Cycle Impact Assessment (LCIA)



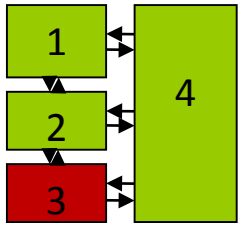


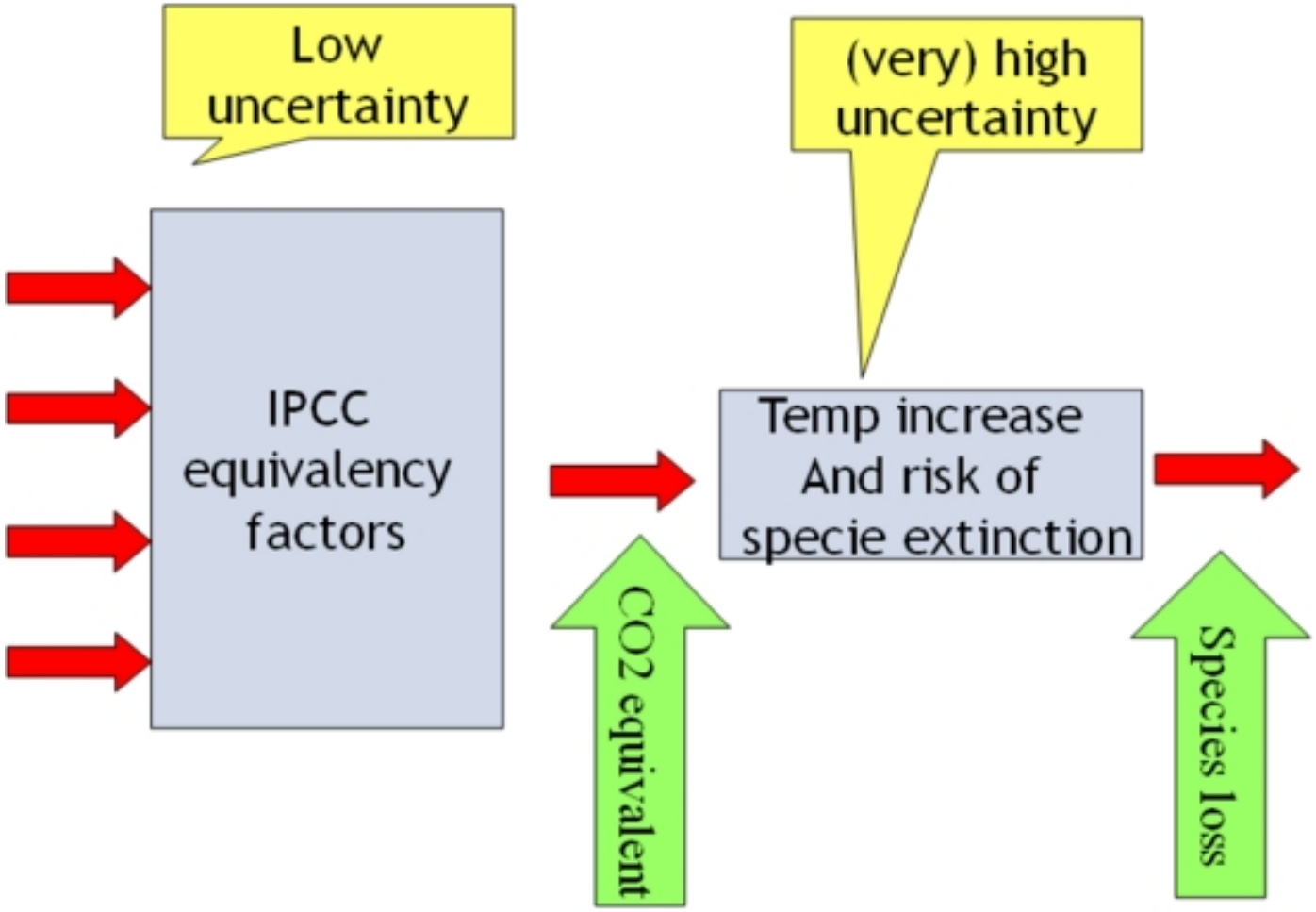

# Life Cycle Impact Assessment

- ~~The life~~ cycle inventory: all elementary flows, e.g.:
  - Inputs: Coal, iron ore, energy, biomass, etc.
  - Outputs: $CO_2$ and $SO_2$ to air, particles to water, tailings, etc.
- To understand the impact on the environment, we need to know the effect of every elementary stream
- Impact assessment
  a) Identify environmental impact categories
  b) Classification
  c) Characterisation
  d) Normalisation
  e) Weighting

NB: Normalisation and weighting are non-scientific (they are value based).

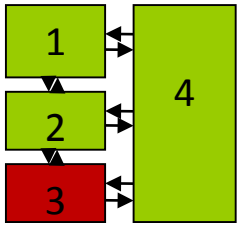
# Midpoint or endpoint?
# Global warming

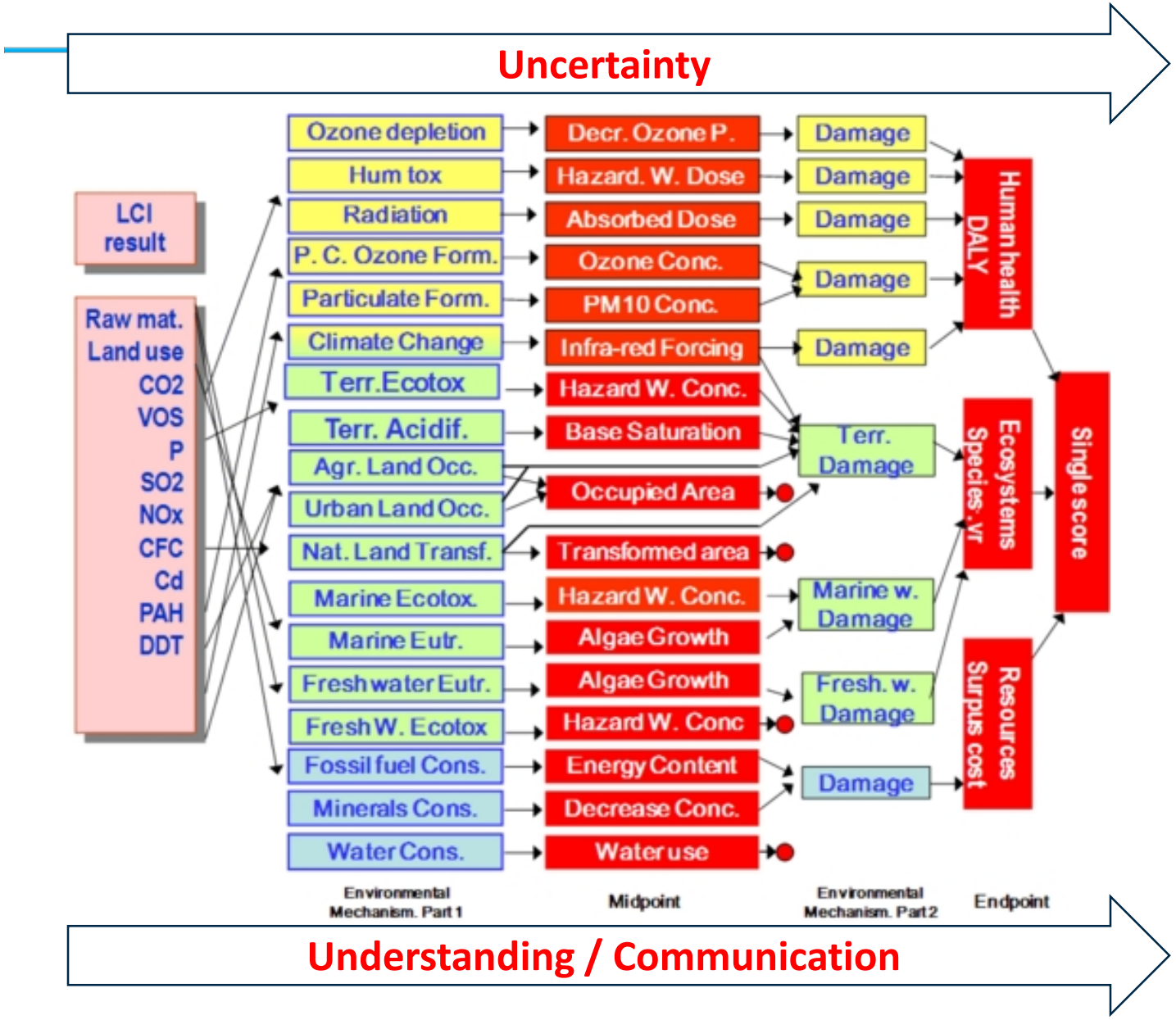


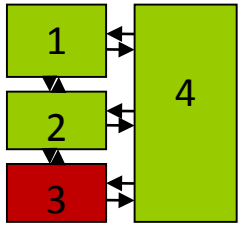




SINTEF

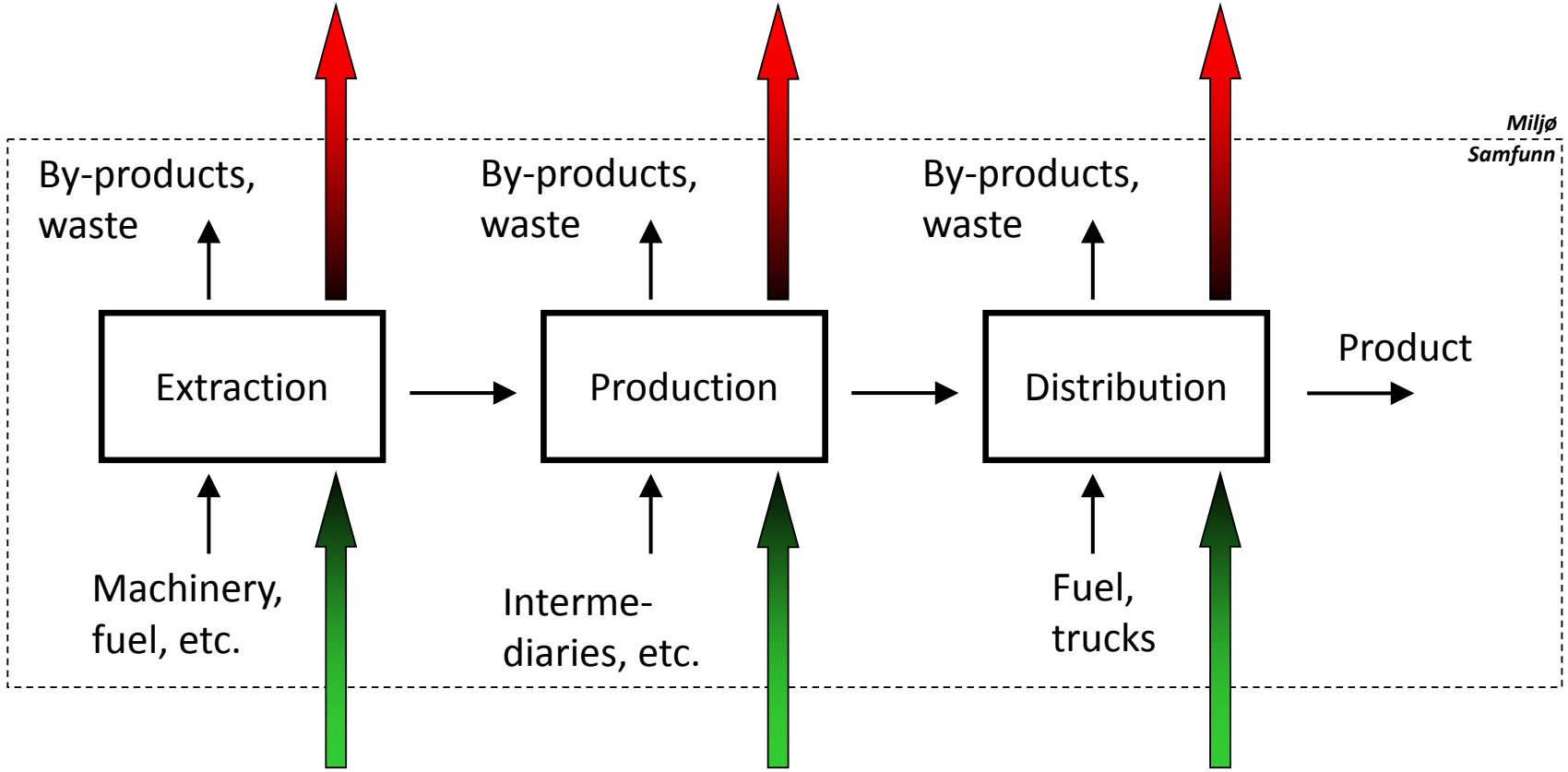
# Midpoint or endpoint?



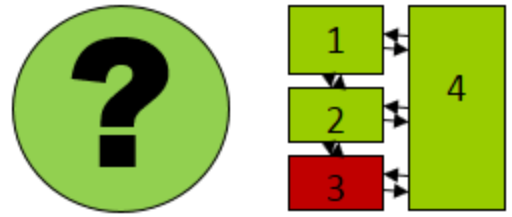

# Example: EPD

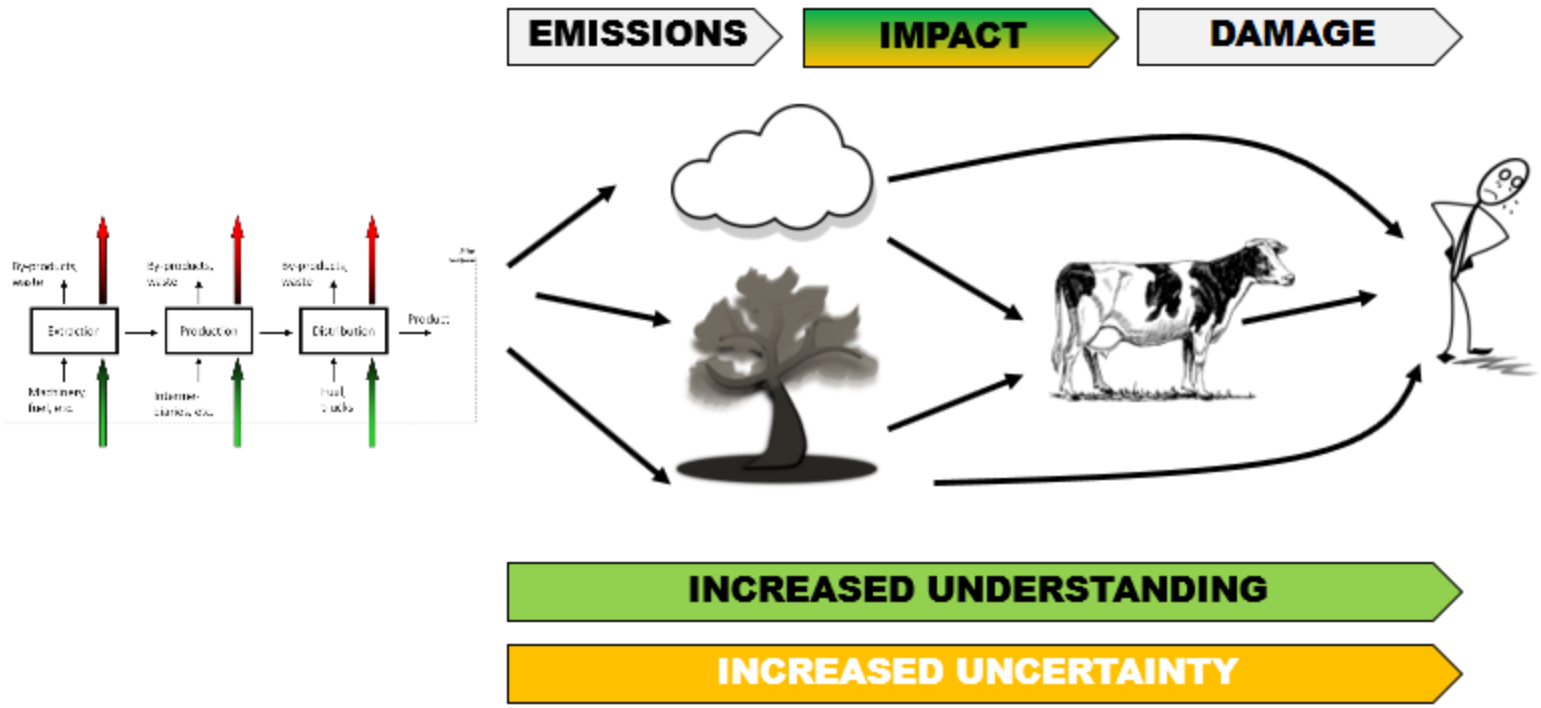



**Modelling the life cycle inventory: What are the elementary flows of our system? *(per functional unit)***

SINTEF

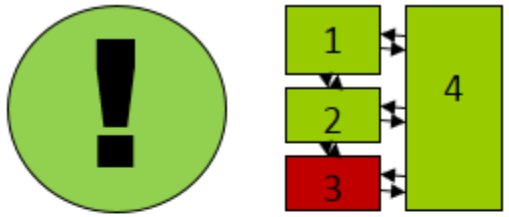
# Example: EPD

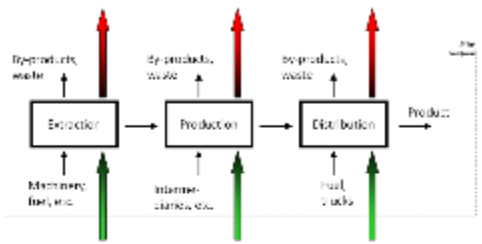


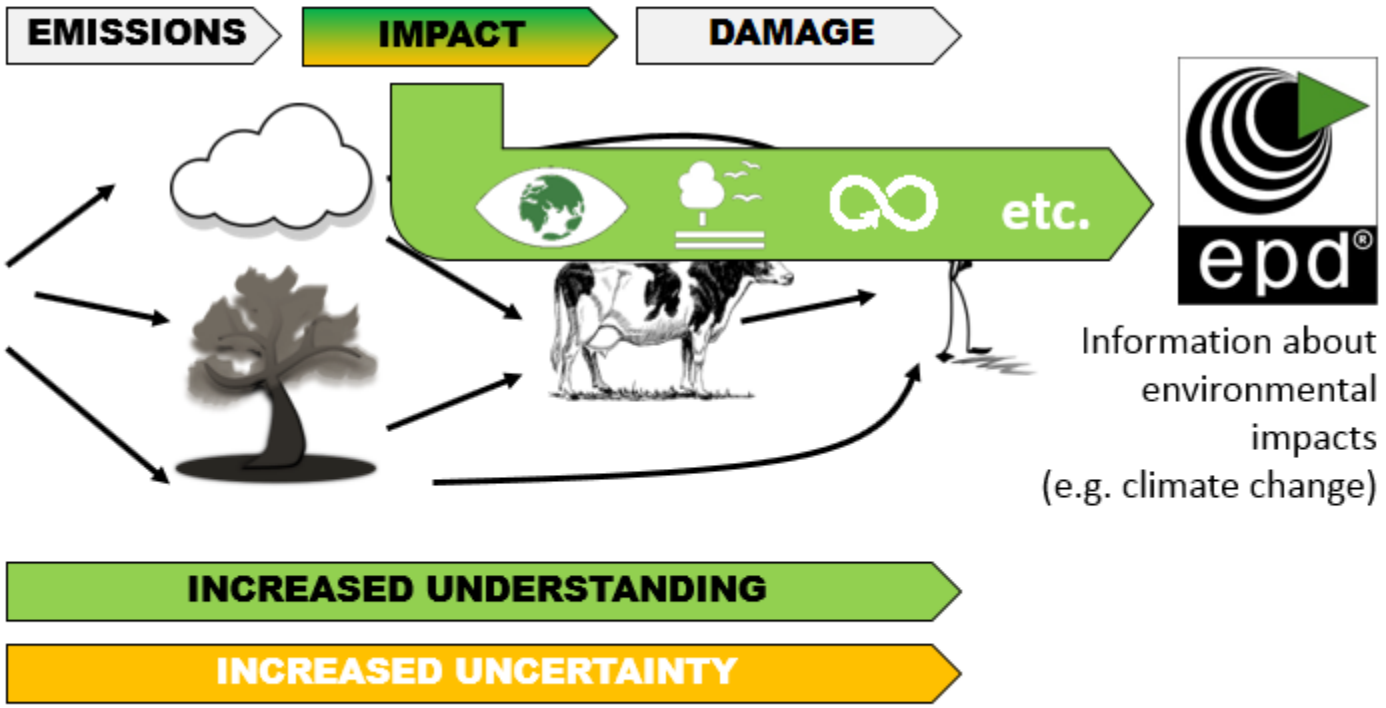




Connecting the inventory to an impact assessment: What is the effect of our system on nature?

# Example: EPD

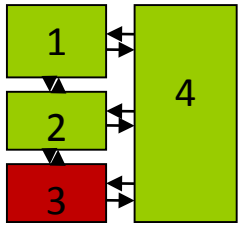


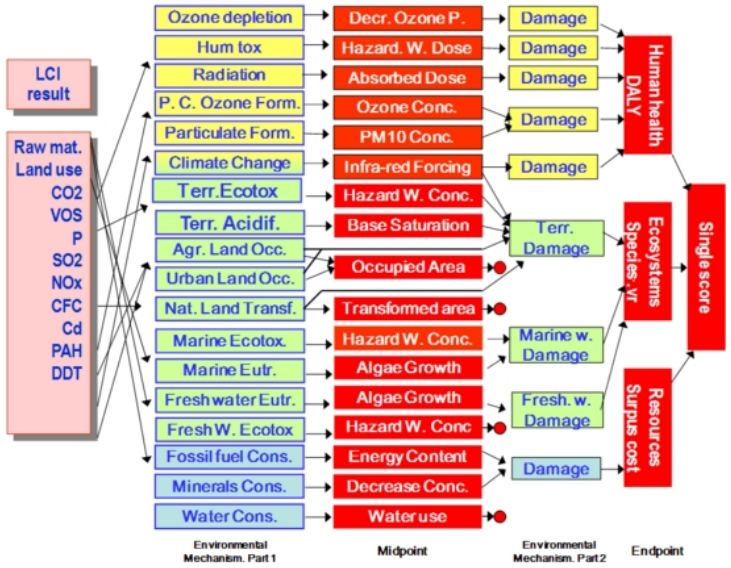

**How far in the cause-effect chain do we go?**

**EPDs stop at the mid-point, to provide a balance between understanding and uncertainty**

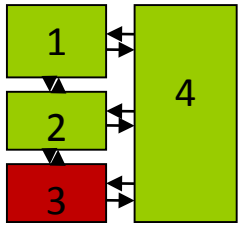



# a) Identify impact categories

Example: copy machine


Climate change?




# b) Classification

Example: copy machine


- CO2: 487 kg
- NOx: 0,013 kg
- SF6: 2*10^-7 kg
- Methane: 1,5 kg
- Particles: 0,3 kg
- Propane: 0,01 kg
- NMVOC: 0,6 kg
- etc.

- CO2: 3243 kg
- NOx: 0,11 kg
- SF6: 6*10^-7 kg
- Methane: 9 kg
- Particles: 5,3 kg
- Propane: 0,03 kg
- NMVOC: 5 kg
- etc.

- CO2: 2226 kg
- NOx: 0,05 kg
- SF6: 0 kg
- Methane: 4,8 kg
- Particles: 0,41 kg
- Propane: 0,15 kg
- NMVOC: -0,2 kg
- etc.

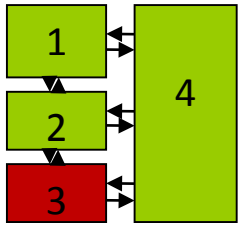
**Contributes to global warming**

(nb: particles also contribute to global warming, but in this model this is not included)

Life cycle inventory, emissions to air

SINTEF

Inventory * char. factor = impact




# c) Characterisation

Production → Use → Disposal

| Manufacturing (kg) | Use (kg) | End of life (kg) |
|---|---|---|
| • CO2: 487 kg | • CO2: 3243 kg | • CO2: 2226 kg |
| • NOx: 0,013 kg | • NOx: 0,11 kg | • NOx: 0,05 kg |
| • SF6: 2*10^-7 kg | • SF6: 6*10^-7 kg | • SF6: 0 kg |
| • Methane: 1,5 kg | • Methane: 9 kg | • Methane: 4,8 kg |

**Global warming potential:**

1 kg NOx = 296 kg $CO_2$

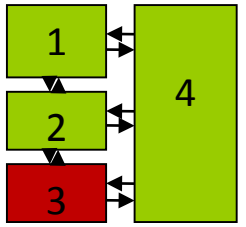
1 kg $SF_6$ = 22200 kg $CO_2$

1 kg methane = 23 kg $CO_2$

| Manufacturing (CO2-eq) | Use (CO2-eq) | End of life (CO2-eq) |
|---|---|---|
| • CO2: 487 kg | • CO2: 3243 kg | • CO2: 2226 kg |
| • NOx: 4 kg | • NOx: 34 kg | • NOx: 15 kg |
| • SF6: 0,005 kg | • SF6: 0,013 kg | • SF6: 0 kg |
| • Methane: 36 kg | • Methane: 211 kg | • Methane: 110 kg |
| Sum: 527,005 kg CO2-eq. | Sum: 3488,013 kg CO2-eq. | Sum: 2351 kg CO2-eq. |

SINTEF

Characterisation: Converting all emissions to a common unit. For global warming, CO2-equivalents are common.

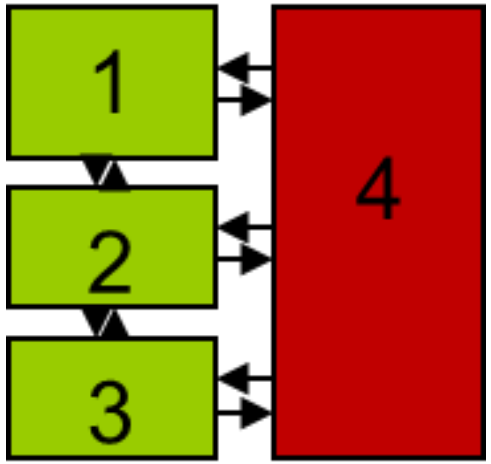


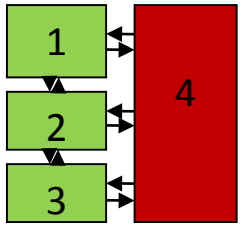

# d) Normalisation
# e) Weighting

- Normalisation
  - Relative impact, to better understand, e.g.
    - Relative to total Norwegian emissions, industry average, product category average, best available, etc.
- Weighting
  - Aggregating impact categories to single score indicator.
  - Example, German expert evaluation:
    - Abiotic Depletion (ADP) 1,5
    - Acidification Potential (AP) 4
    - Eutrophication Potential (EP) 7
    - Global Warming Potential (GWP) 10
    - Ozone Layer Depletion Potential (ODP) 4
    - Photochem. Ozone Creation Potential (POCP) 1,5
- *NB: There is no scientific approach to normalisation and weighting. It is always value based.*

SINTEF

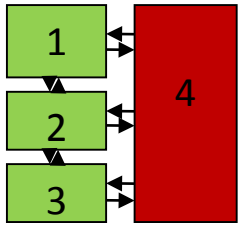
# 4. Interpretation






# Interpretation

- Get to know the relevant production system(s) in your model!
- Leave time for multiple iterations on goal and scope + inventory
- New results can lead to new understanding
- Errors will occur, analyze often to identify errors.



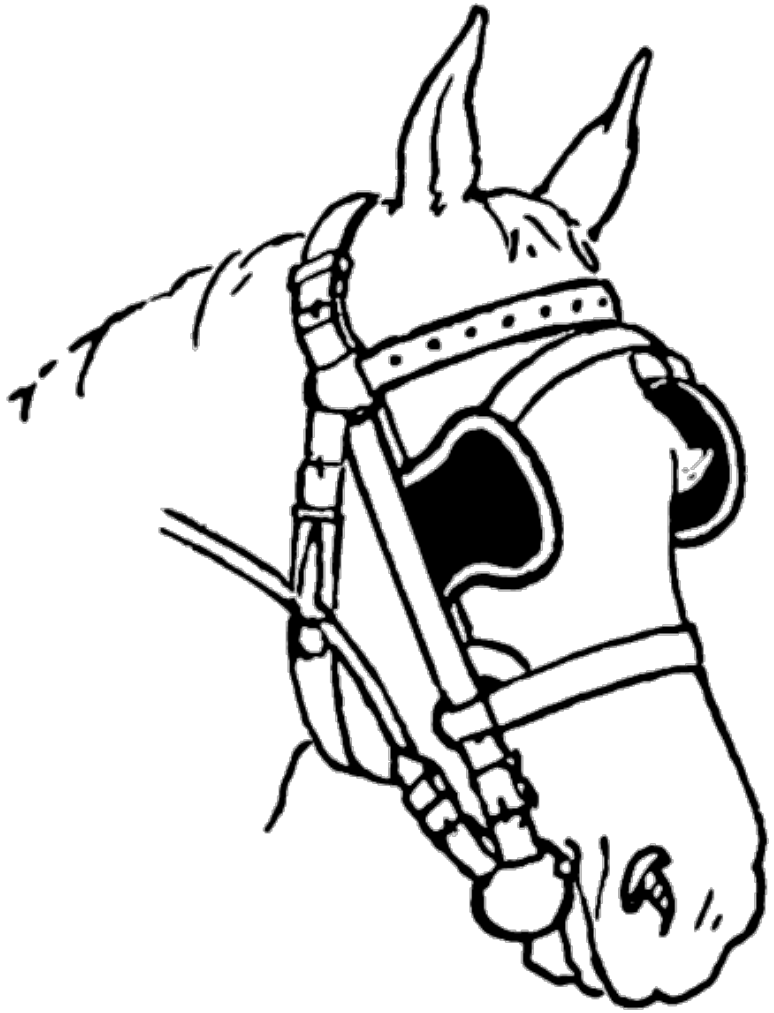

# Interpretation

- Results can be broken down in all sorts of way by simple mathematical operation
- Process/life cycle stage contribution
- Stressor contribution (aka elementary flow contribution)
- Uncertainty (monte-carlo simulation) and sensitivity analysis
- Advanced breakdowns (requires matlab or similar):
- Contributions from processes upstream of foreground processes/value chain
- Structural path analysis (SPA)

# Carbon footprint

# $CO_2$ emissions and buildings

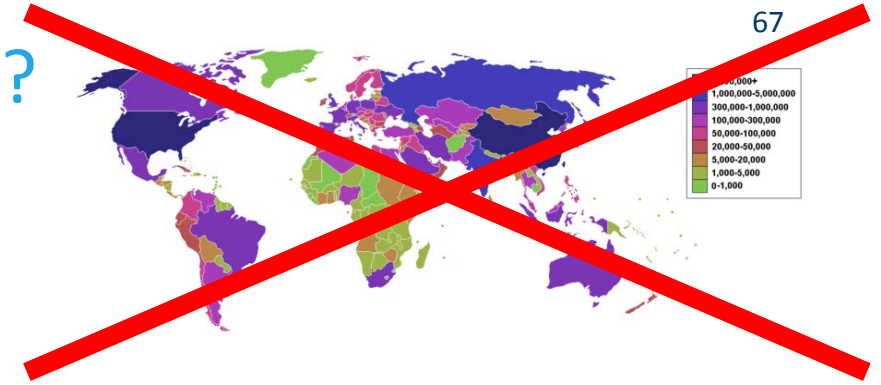
Carbon footprint is not all. If we do not consider this, we risk problem shifting.



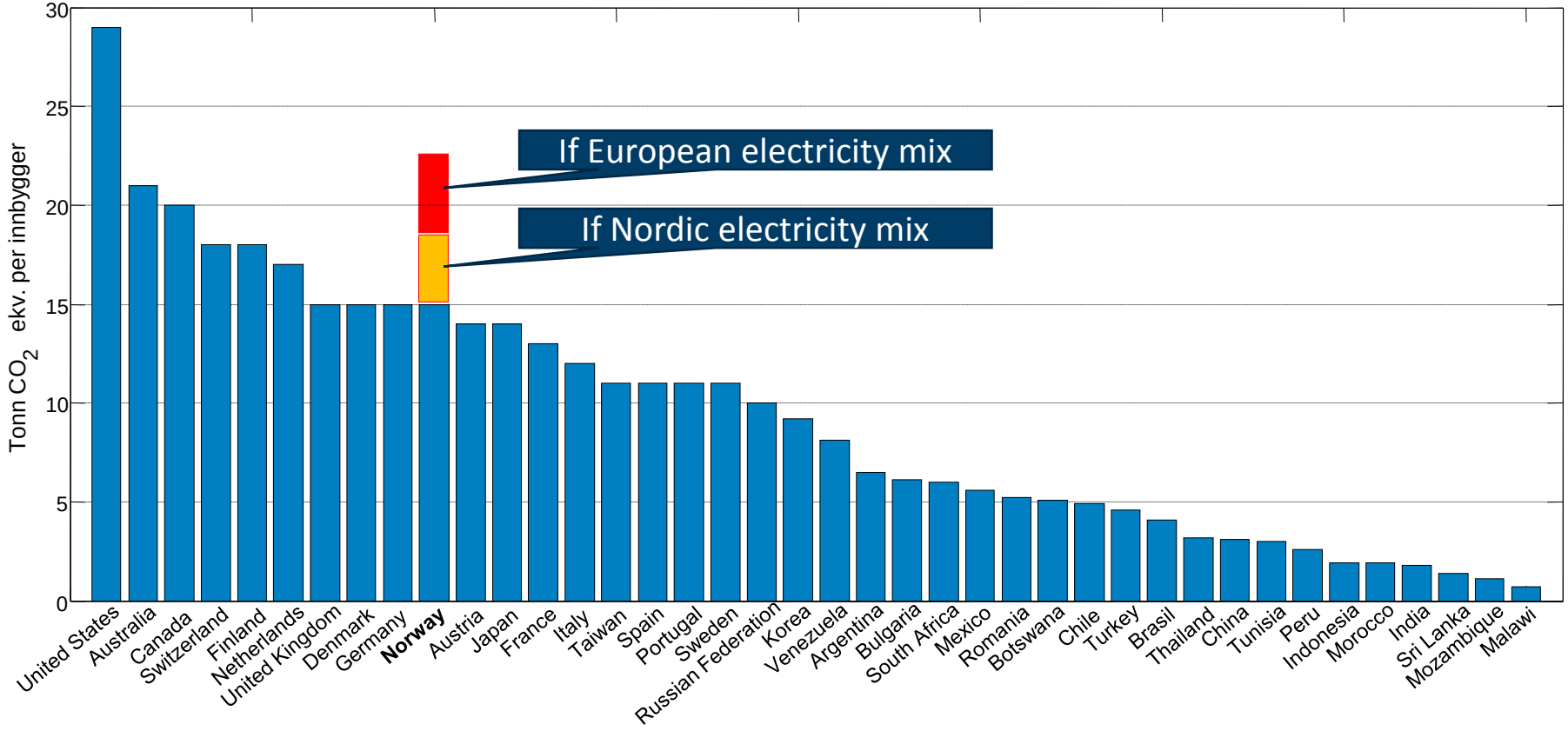
But: We can't use that as an excuse to not meet our carbon footprint goals.

# Why a life cycle perspective? Example, climate

Emissions:

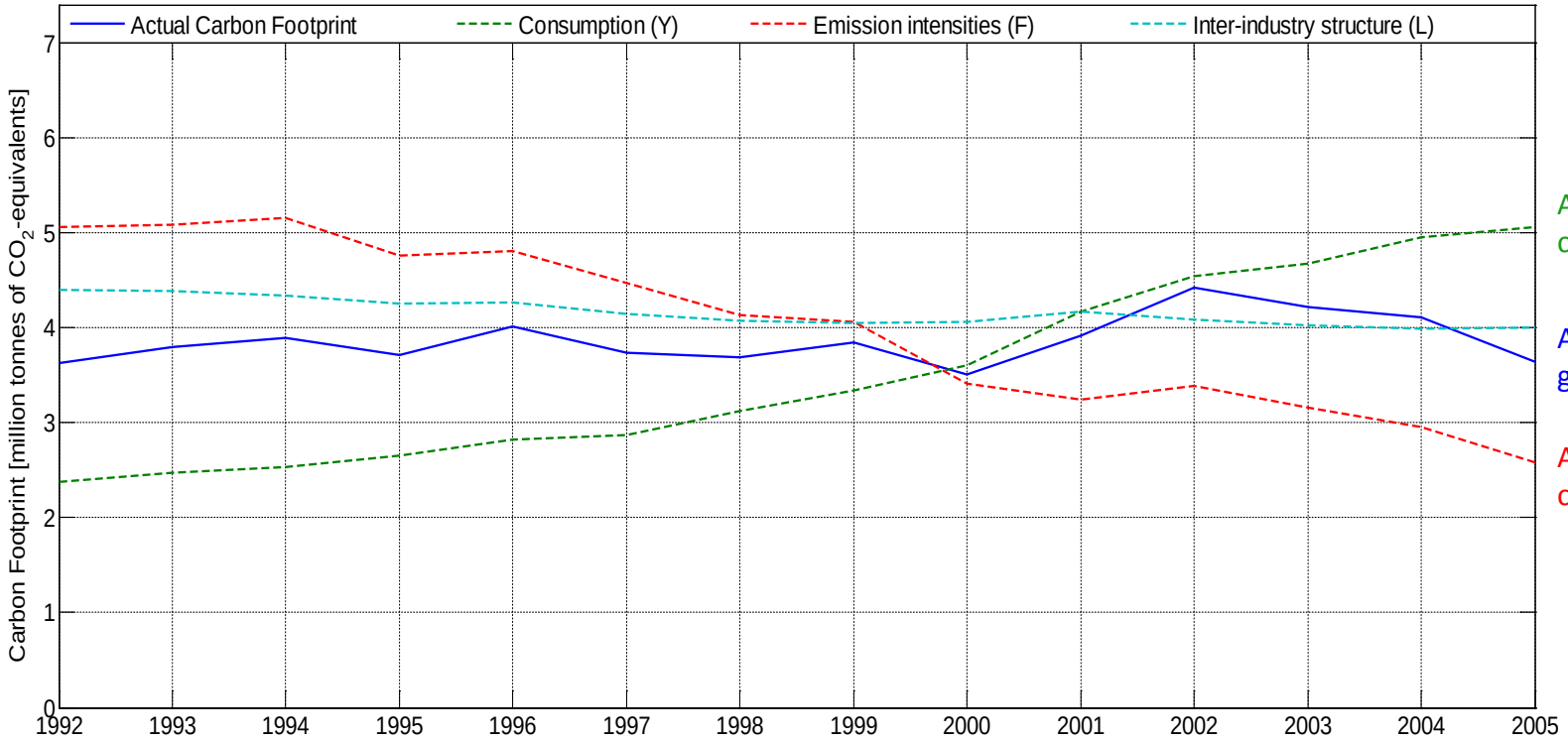



Who causes emissions:




SINTEF

# Norwegian carbon footprint over time




Actual consumption, constant technology

Actual greenhouse gas emissions

Actual technology, constant consump.

Kilde: HN Larsen

SINTEF

# GHG emissions from building materials

*"Embodied energy is the sum of all the energy required to produce any goods or services, considered as if that energy was incorporated or 'embodied' in the product itself. " - Wikipedia*

*Embodied emissions are both due to emissions from the use of energy as well as emissions from non-energy-related processes.*

- *CO2 emissions from the chemical production process of cement*
  - chemical conversion of limestone (calcium carbonate) to calcium oxide (the principal component of cement) $CaCO3+heat \rightarrow CaO+CO2$

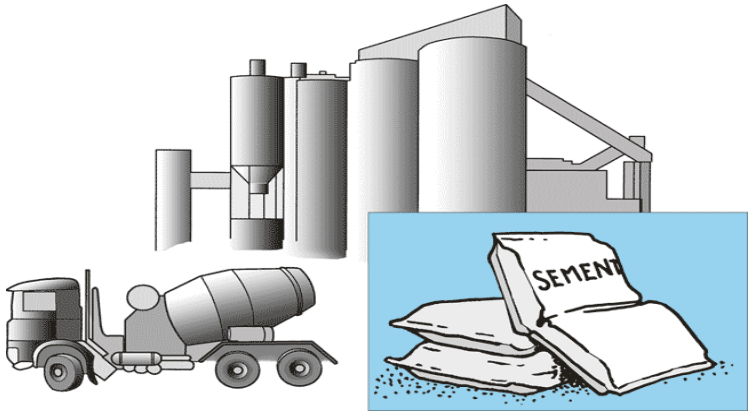
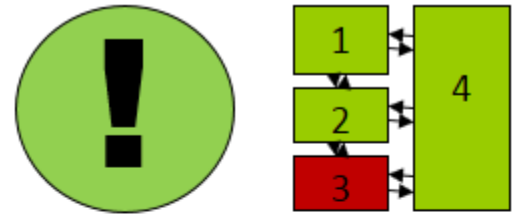


Illustration: SINTEF Byggforsk

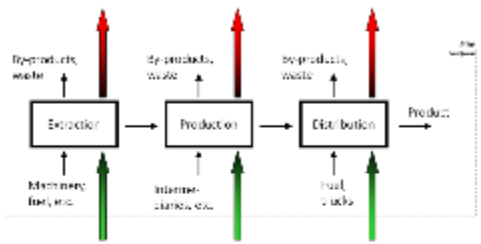
*A rose by any other name: Carbon footprint, greenhouse gas emissions, CO2, embodied carbon, GWP, etc.*

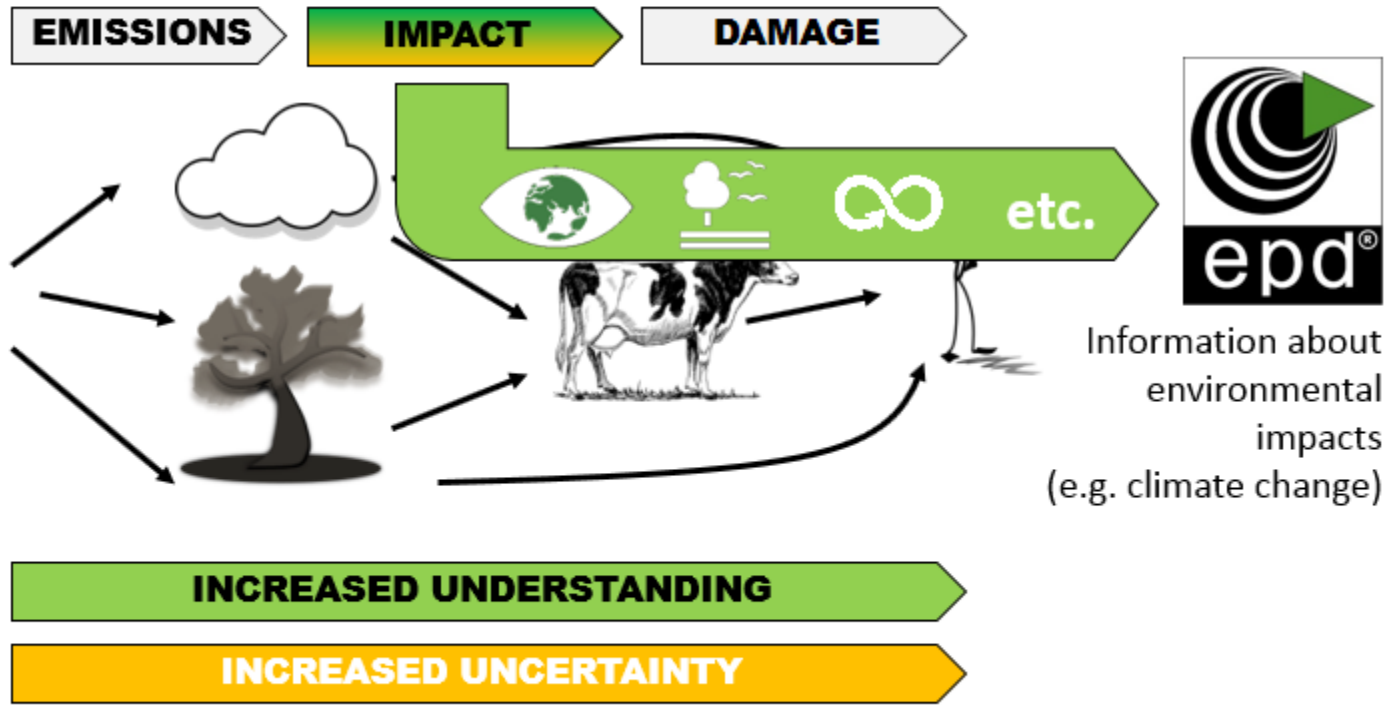
SINTEF

# Example: EPD



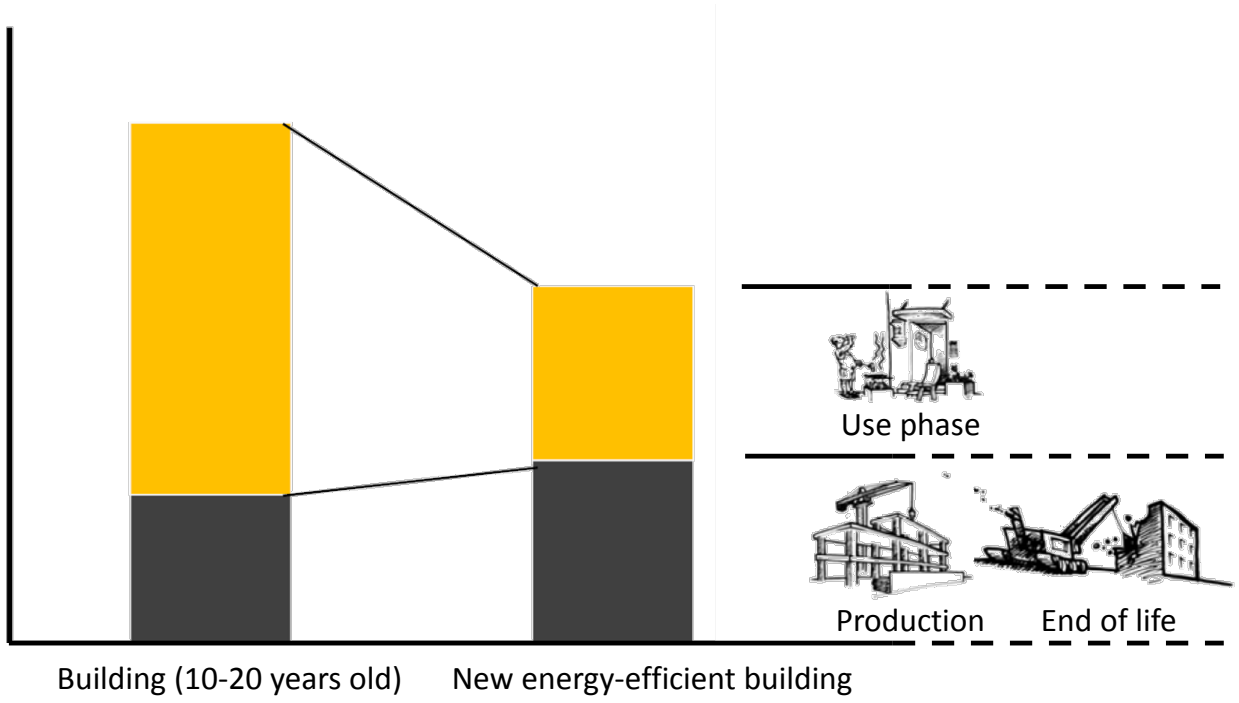


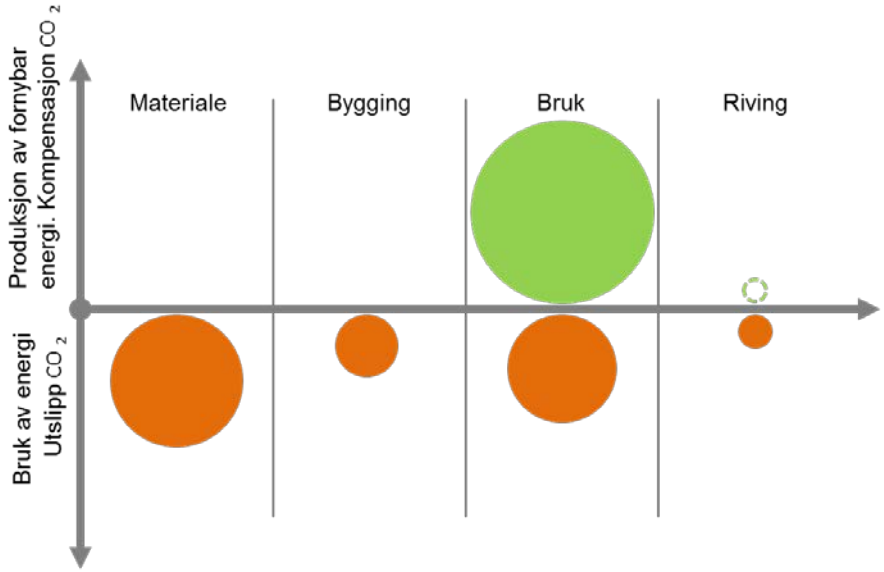



SINTEF

# Footprint?






SINTEF

# Ambition: Carbon footprint

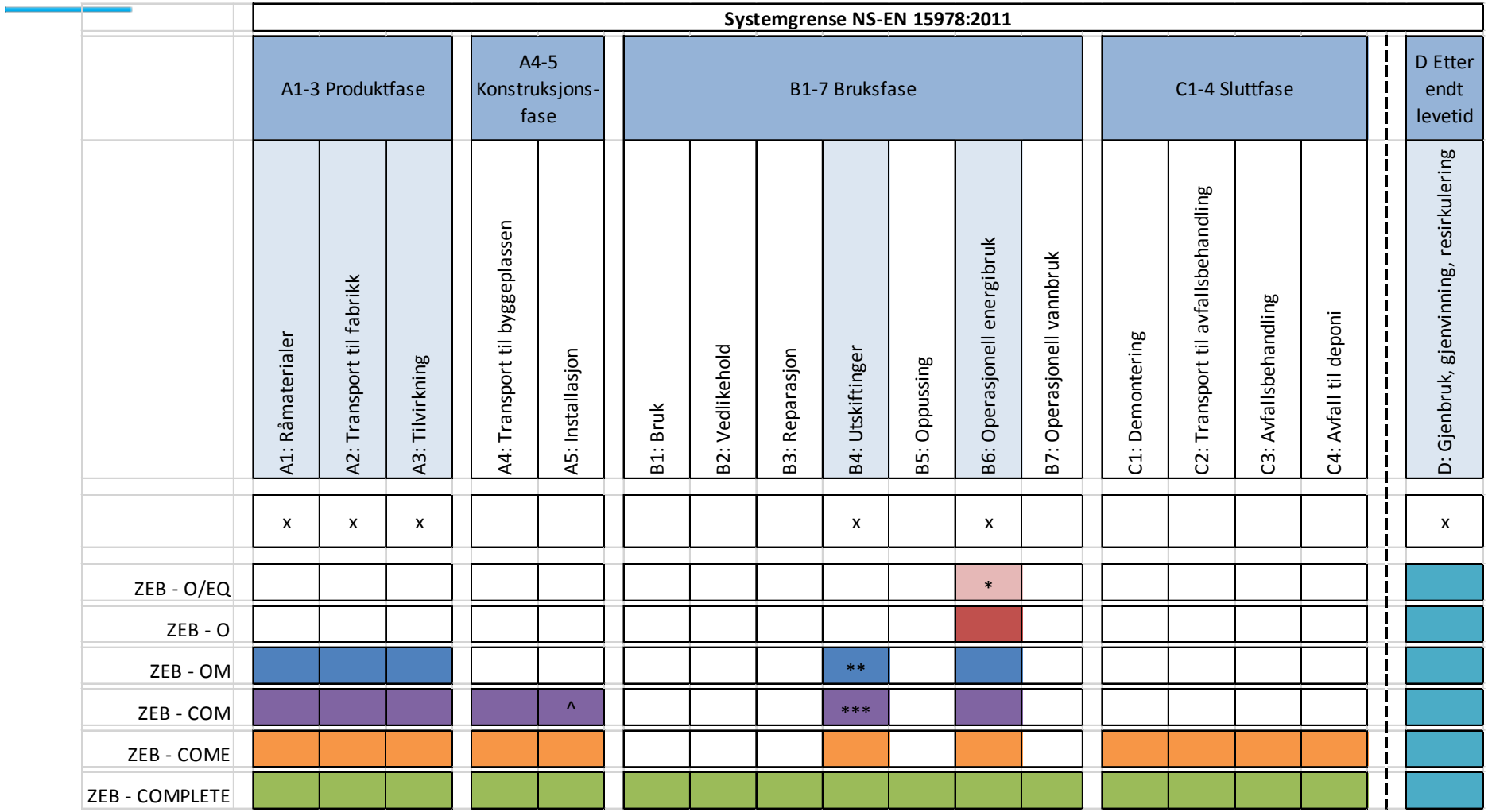
| Systemgrense NS-EN 15978:2011 | | | | | |
|---|---|---|---|---|---|
| A1-3 Produktfase | A4-5 Konstruksjons-fase | B1-7 Bruksfase | | C1-4 Sluttfase | D Etter endt levetid |



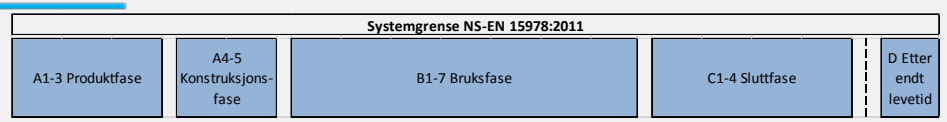
SINTEF

*Example*

# Ambition: ZEB *(and what about ZEN?)*



# Ambition, system boundaries

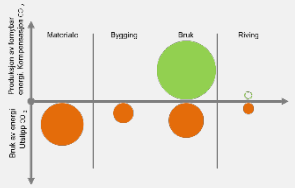


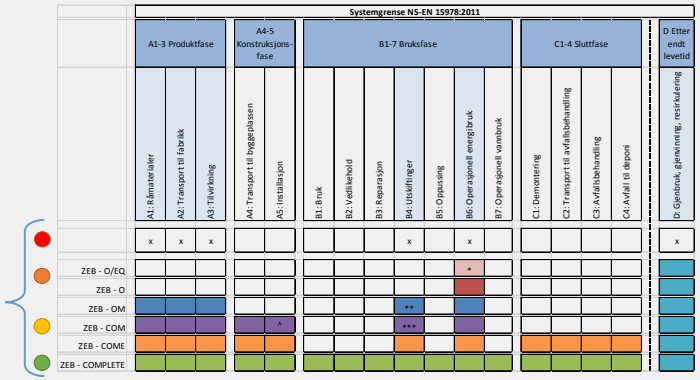

**What do you include in your carbon footprint?**

*Recommendation: At least A1-A3, B4 and B6*

# Ambition, performance

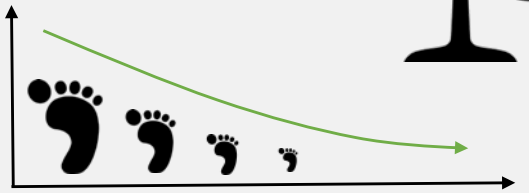
**What is your ambition?**




ZEB-ambition?

Reduction compared to a reference building?

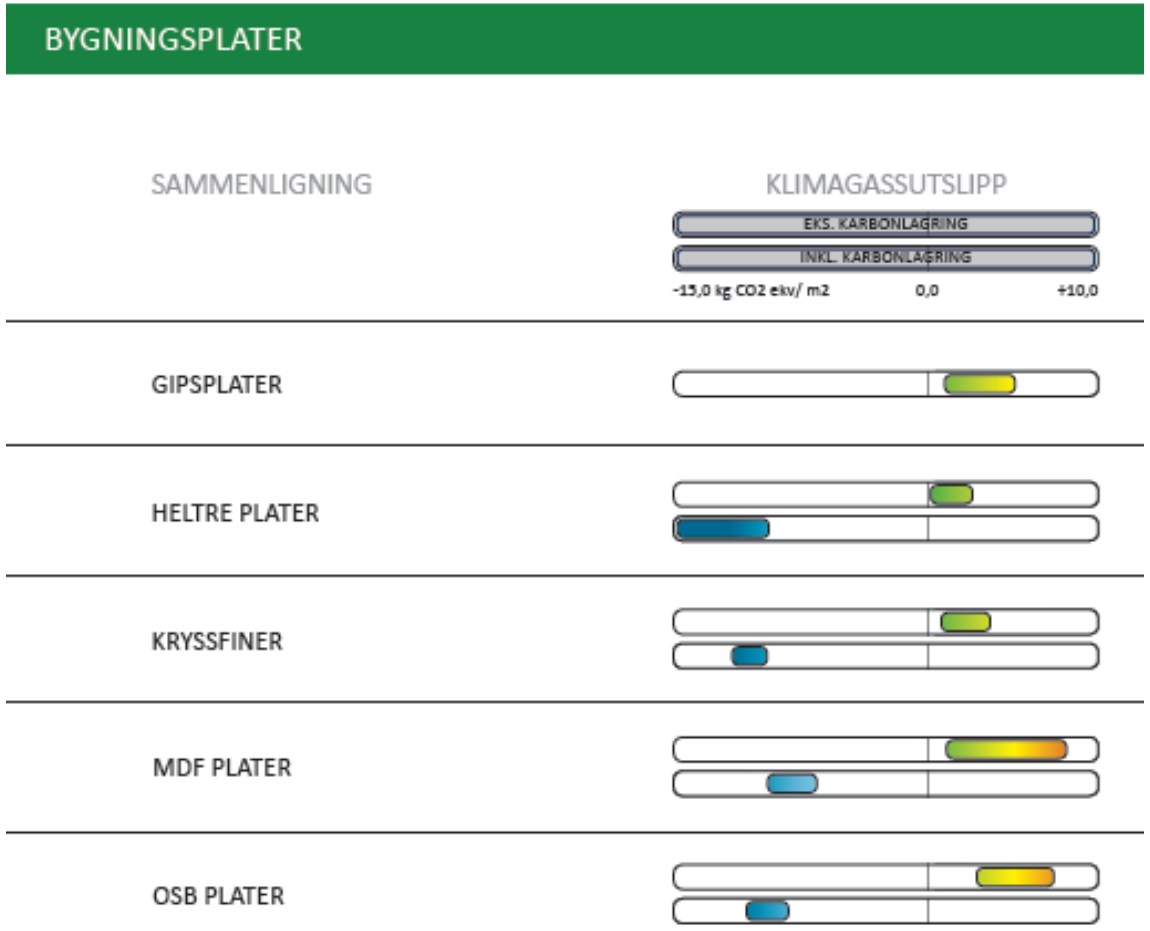


Klimafotspor



SINTEF

# GHG emissions from building materials




Green material guide: Method for selecting environmentally friendly materials and products in construction projects

GHG emissions from building boards production (A1-A3) typically vary 0- 5 kg CO2 equivalents per square meter plate.

Grønn Materialguide, **version 2.1, financed by** © Direktorat for Byggkvalitet (DiBK), Husbanken, Grønn Byggallianse og Context AS. Juni 2017

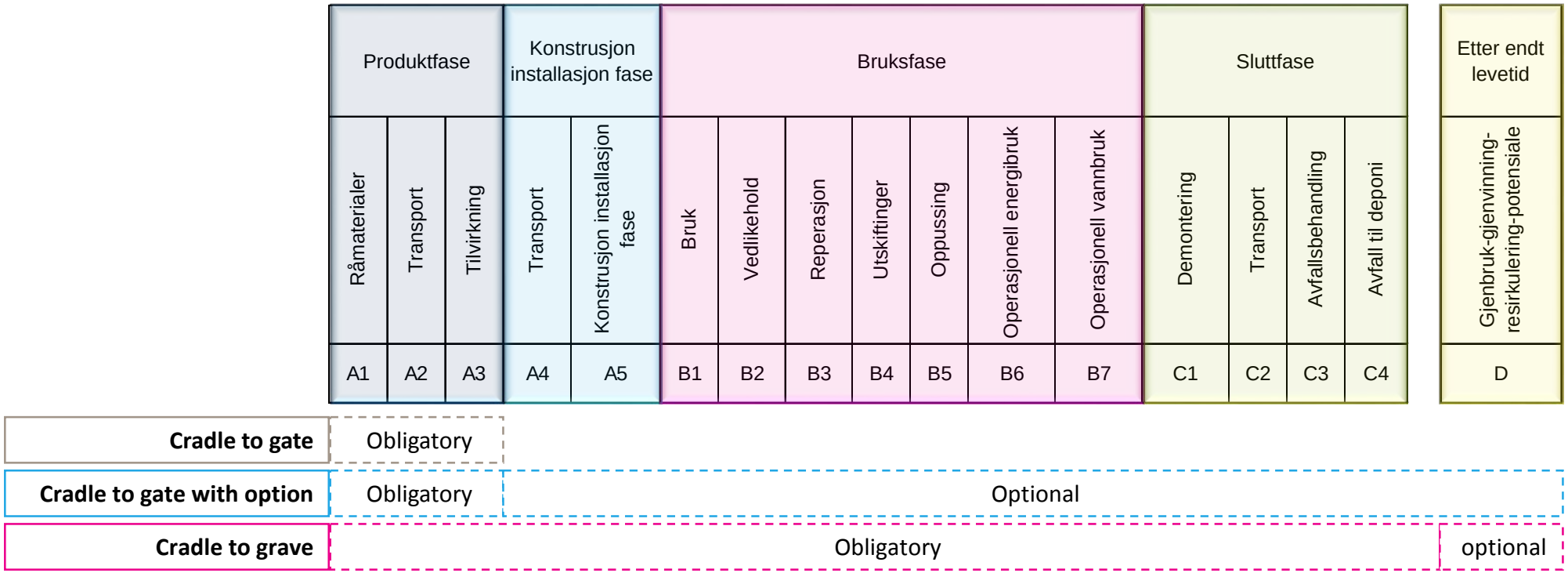
SINTEF

# Materials

- Think function, not product or material
- Fair comparisons
  - Equal system boundaries
  - In a building context

- Life cycle perspective:
  - A house has a study period of 60 years. A door has a referance lifetime of 40 years.
    **How many doors do you need?**

# Documentation: Typically from EPD (in ZEB)



# Example, floor constructions

- Life cycle assessment (LCA): Carbon footprint
  - Function instead of product or material
  - Data from Environmental Product Declarations (EPDs)
  - Monte Carlo analysis
- Constructions
  - Joist span of 7.2 meter
  - Sound insulation: 53 dB
  - Fire resistance: REI 90

**NB: Some of the constructions can overfulfill the requirements.**
**All the constructions can be optimised.**

*From:*
*Composite floors in urban buildings: Options for a low carbon building design*
*Skaar, C., Solem, B. og Rüther, P. (2017) presentert på Forum Wood Building Nordic 2017*



SINTEF

# System boundaries

Included

Not relevant

Not included

| Product stage | | | Assembly stage | | Use stage | | | | | | | End of life stage | | | | Beyond the system boundaries |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Raw materials | Transport | Manufacturing | Transport | Assembly | Use | Maintenance | Repair | Replacement | Refurbishment | Operational energy use | Operational water use | De-construction demolition | Transport | Waste processing | Disposal | Reuse-Recovery-Recycling-potential |
| A1 | A2 | A3 | A4 | A5 | B1 | B2 | B3 | B4 | B5 | B6 | B7 | C1 | C2 | C3 | C4 | D |



SINTEF

# System boundaries

Included

Not relevant

Not included

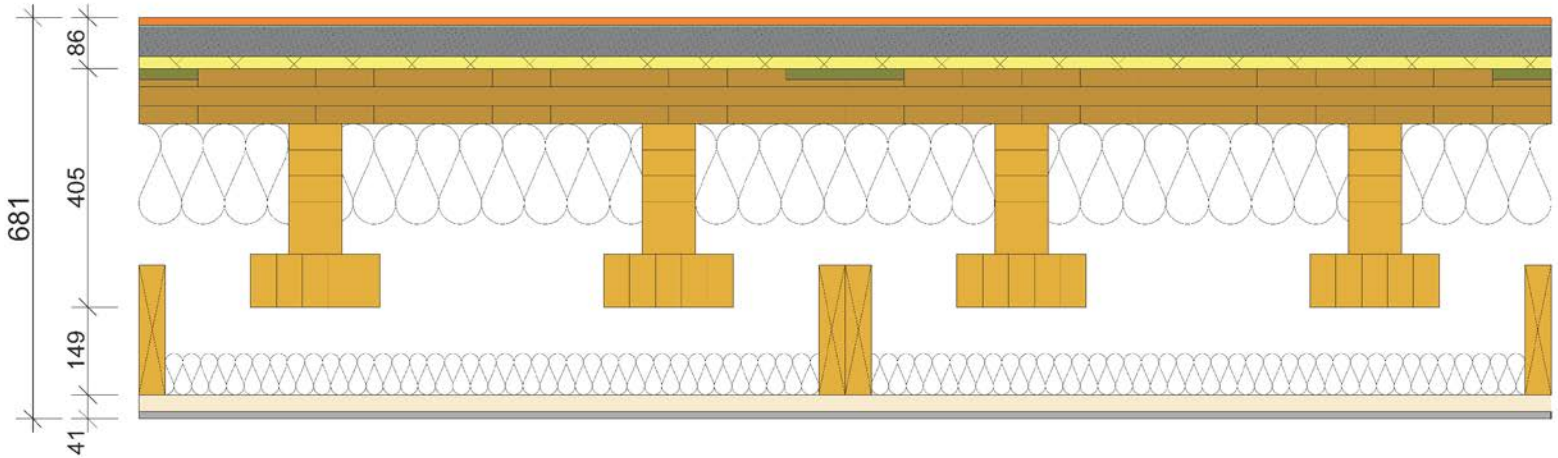
| Product stage | | | Assembly stage | | Use stage | | | | | | | End of life stage | | | | Beyond the system boundaries |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Raw materials | Transport | Manufacturing | | | | | Repair | Replacement | Refurbishment | Operational energy use | Operational water use | De-construction demolition | Transport | Waste processing | Disposal | Reuse-Recovery-Recycling-potential |
| A1 | A2 | A3 | A4 | A5 | B1 | B2 | B3 | B4 | B5 | B6 | B7 | C1 | C2 | C3 | C4 | D |

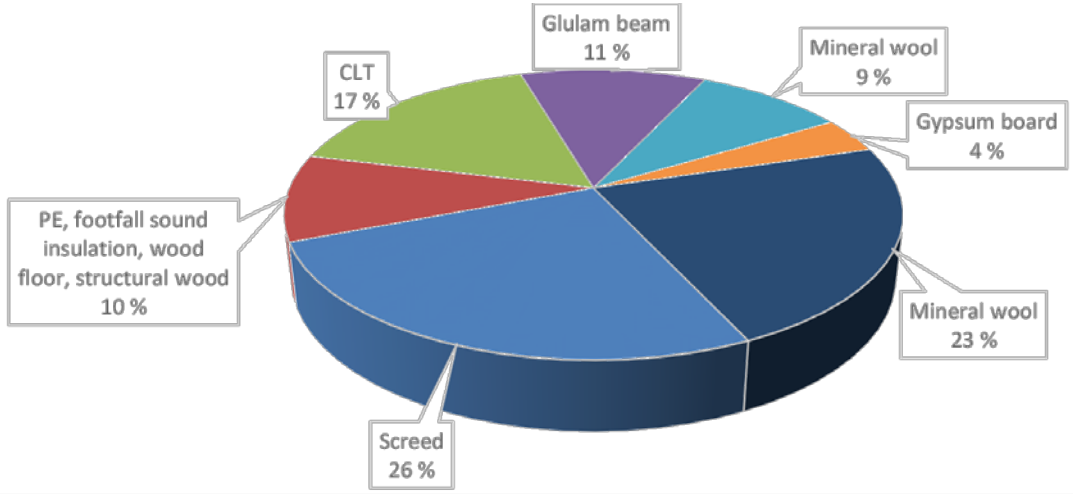
A1-A3



SINTEF

# Construction 1: Cross-laminated timber (CLT)

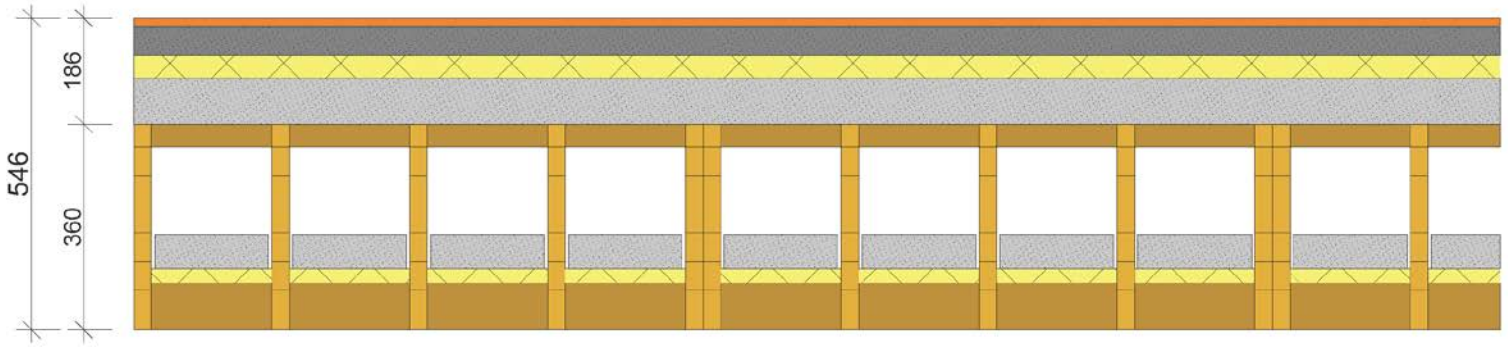


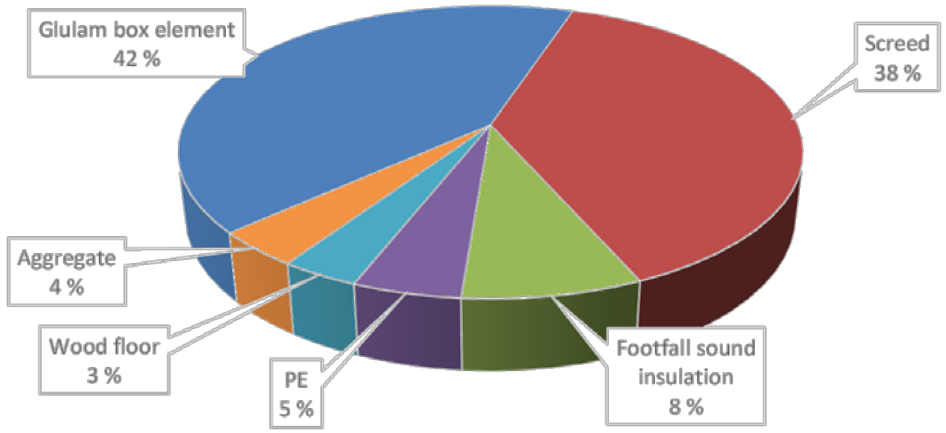





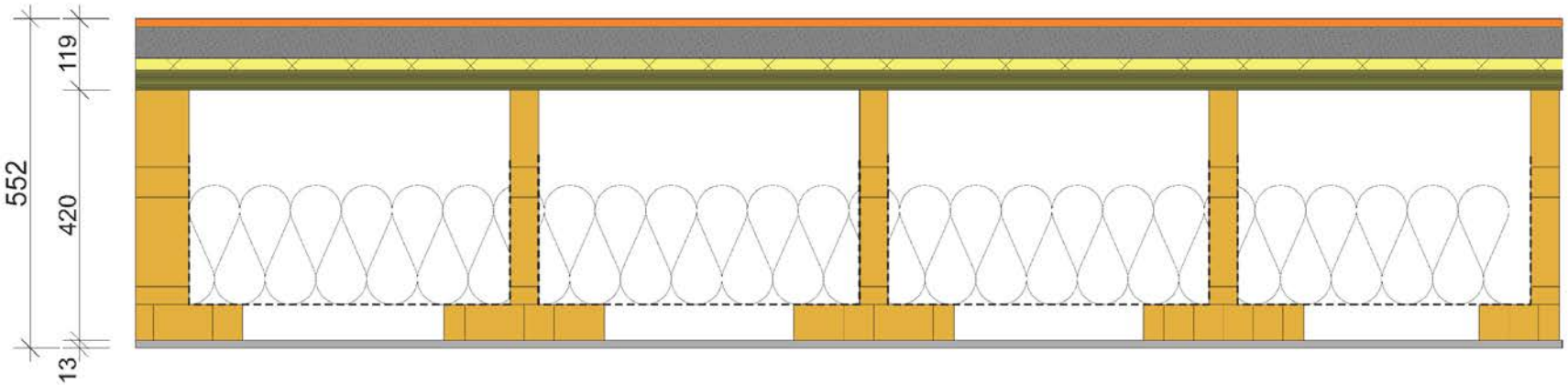

SINTEF

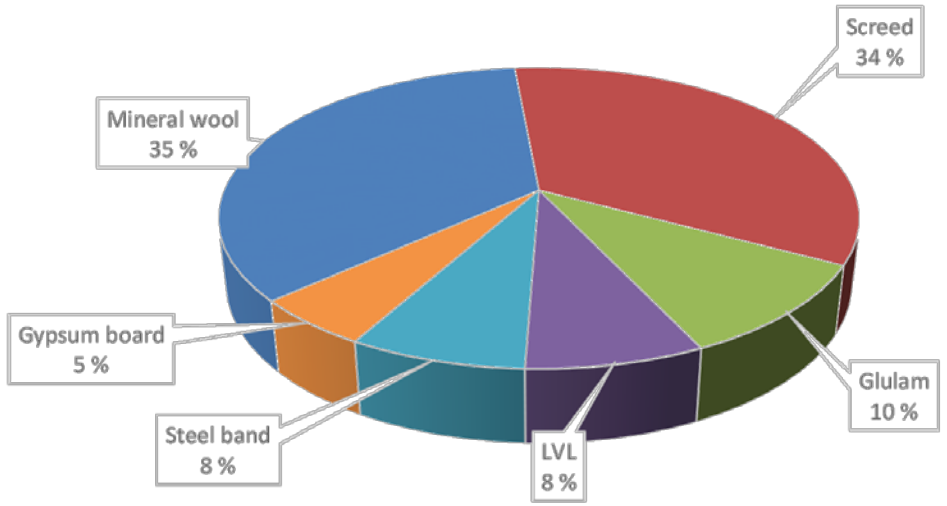
# Construction 2: Timber box element



# Construction 3: Laminated veneer lumber (LVL)

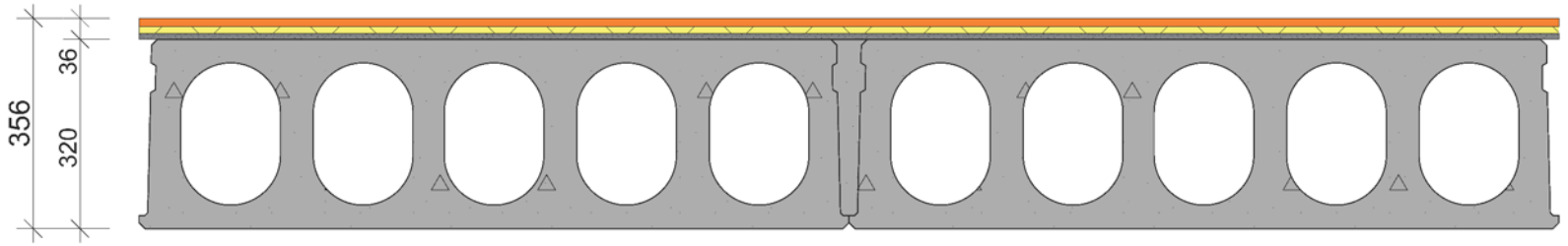


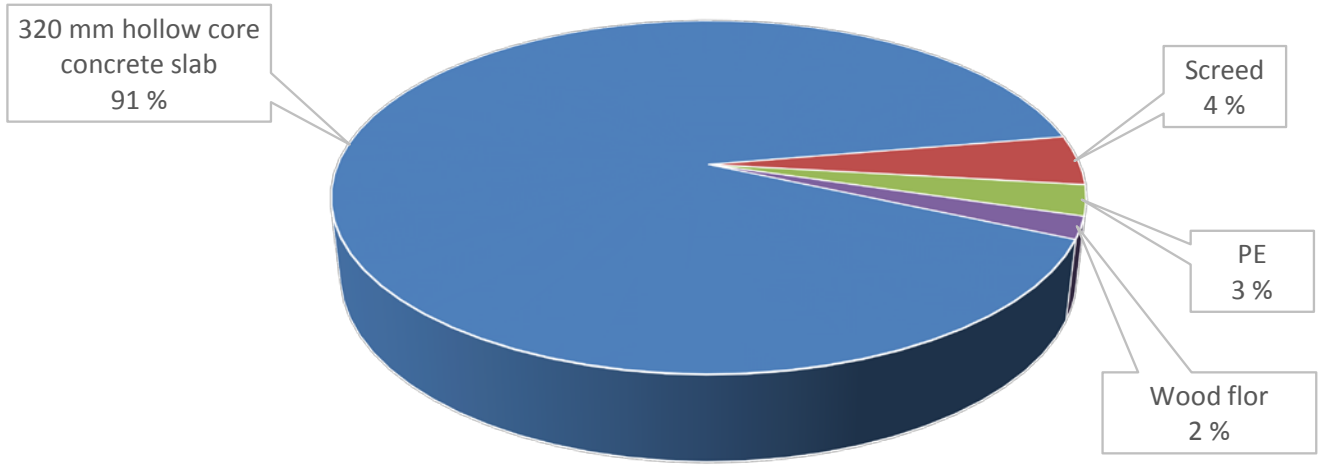






SINTEF

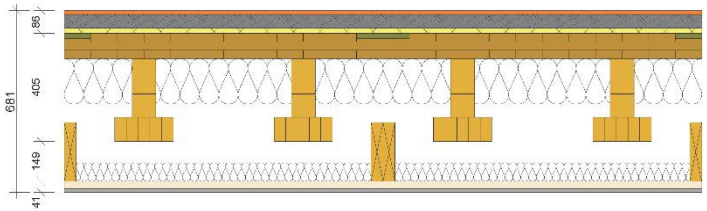
# Construction 4: Hollow core concrete



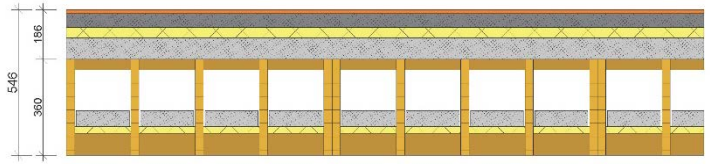



# Results

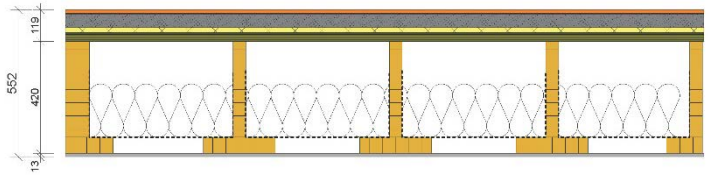
1: Cross-laminated timber (CLT)



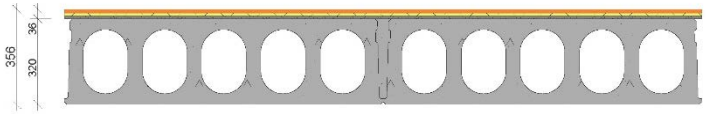

2: Timber box element

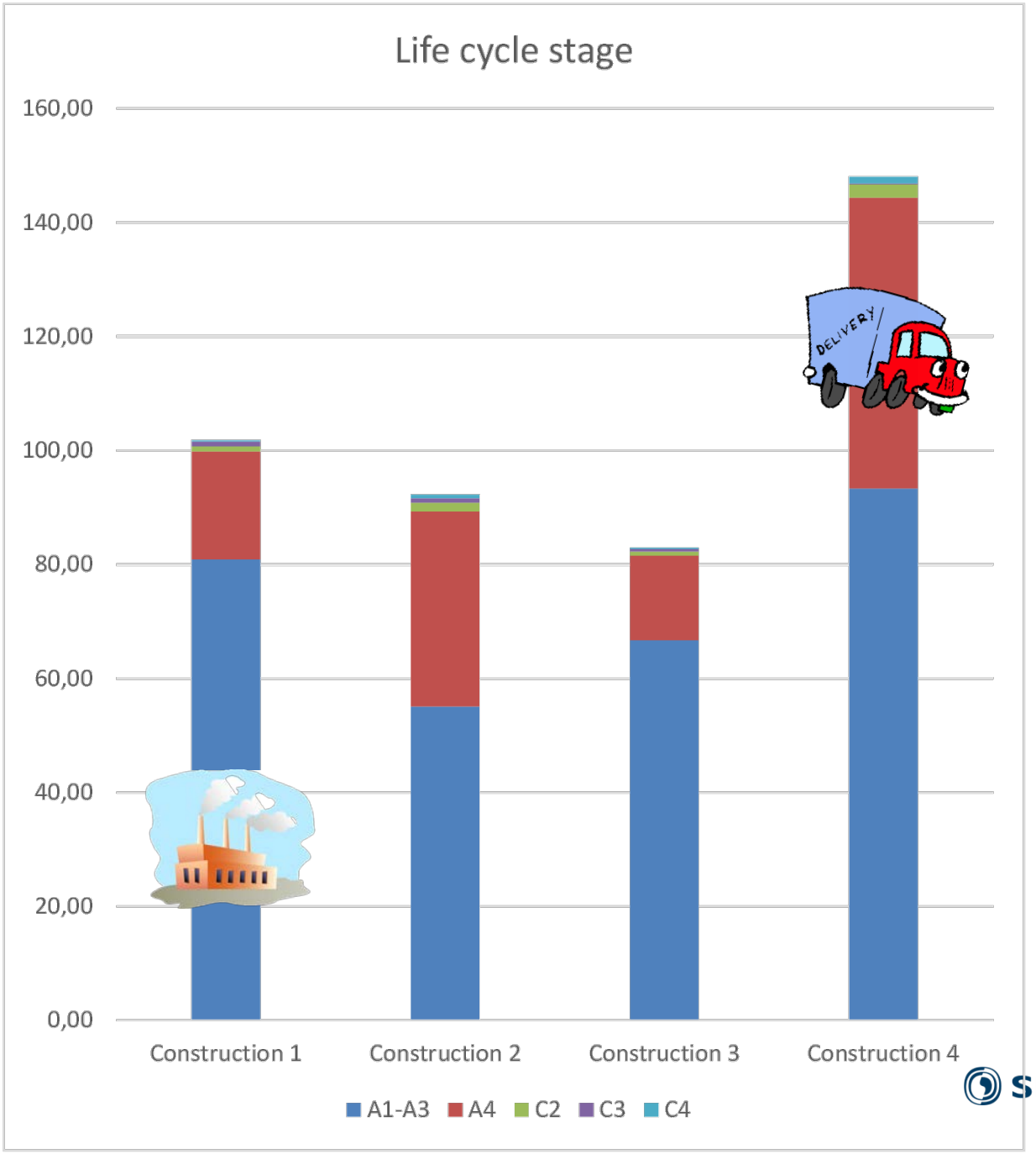



3: Laminated veneer lumber (LVL)




4: Hollow core concrete



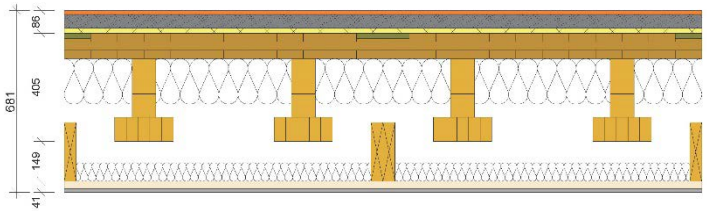





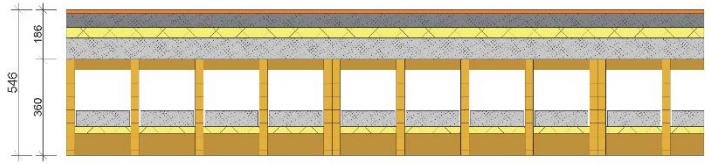

SINTEF

# Results

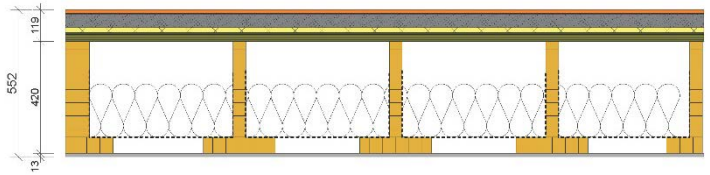
1: Cross-laminated timber (CLT)



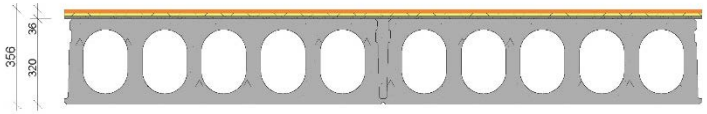

2: Timber box element

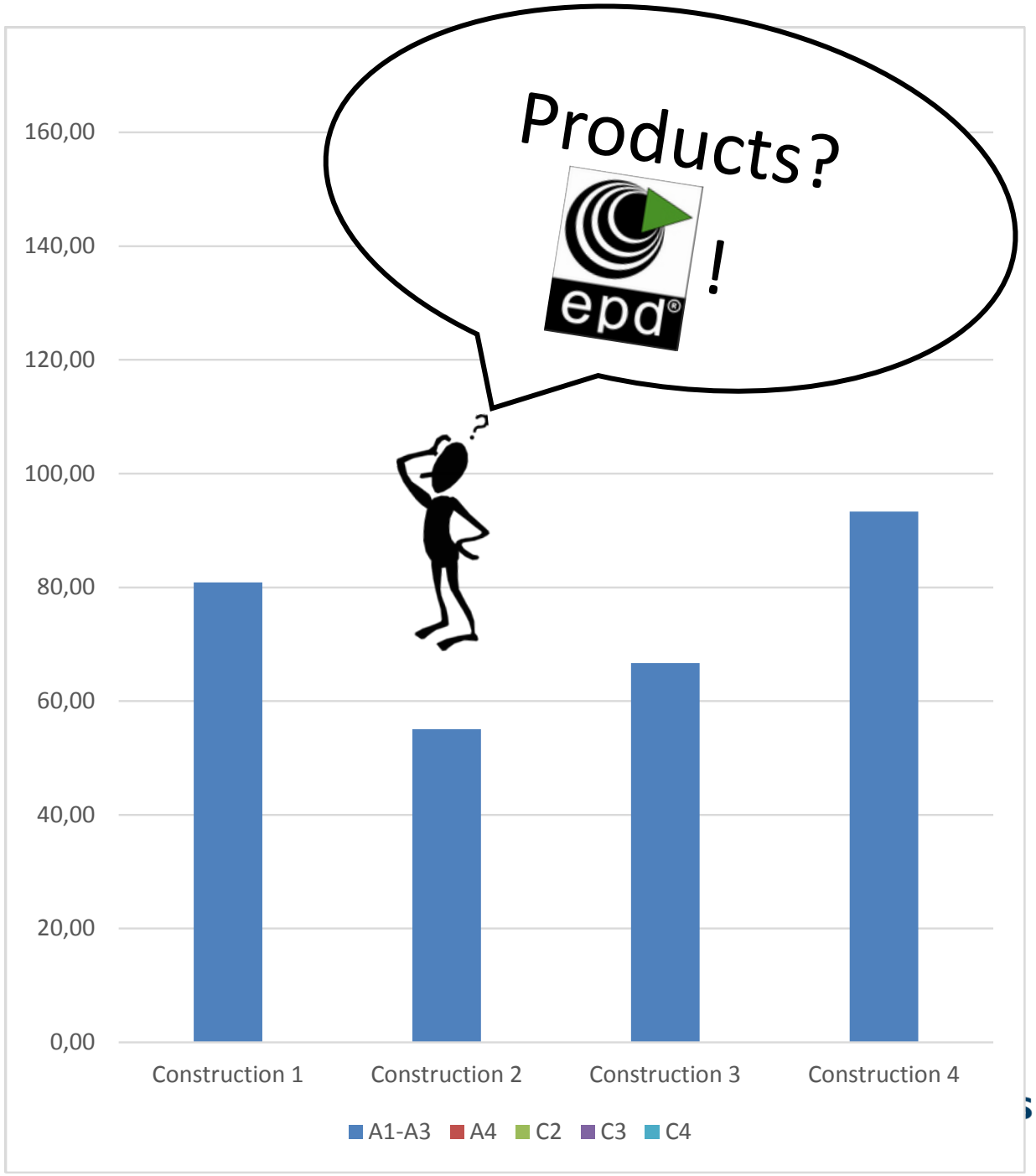



3: Laminated veneer lumber (LVL)




4: Hollow core concrete



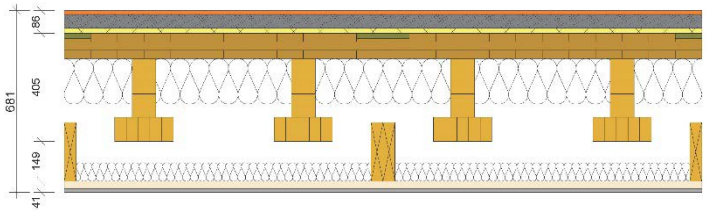





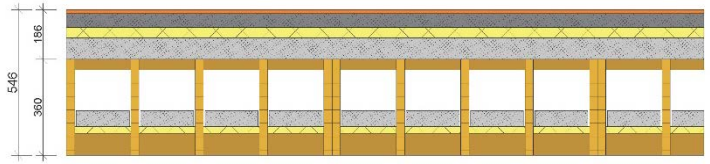

SINTEF

# Results

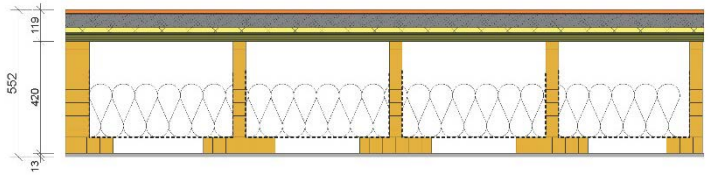
1: Cross-laminated timber (CLT)



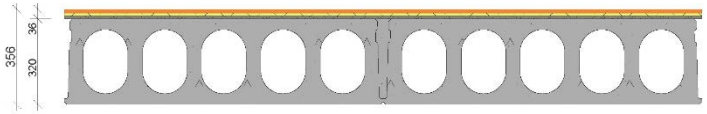

2: Timber box element

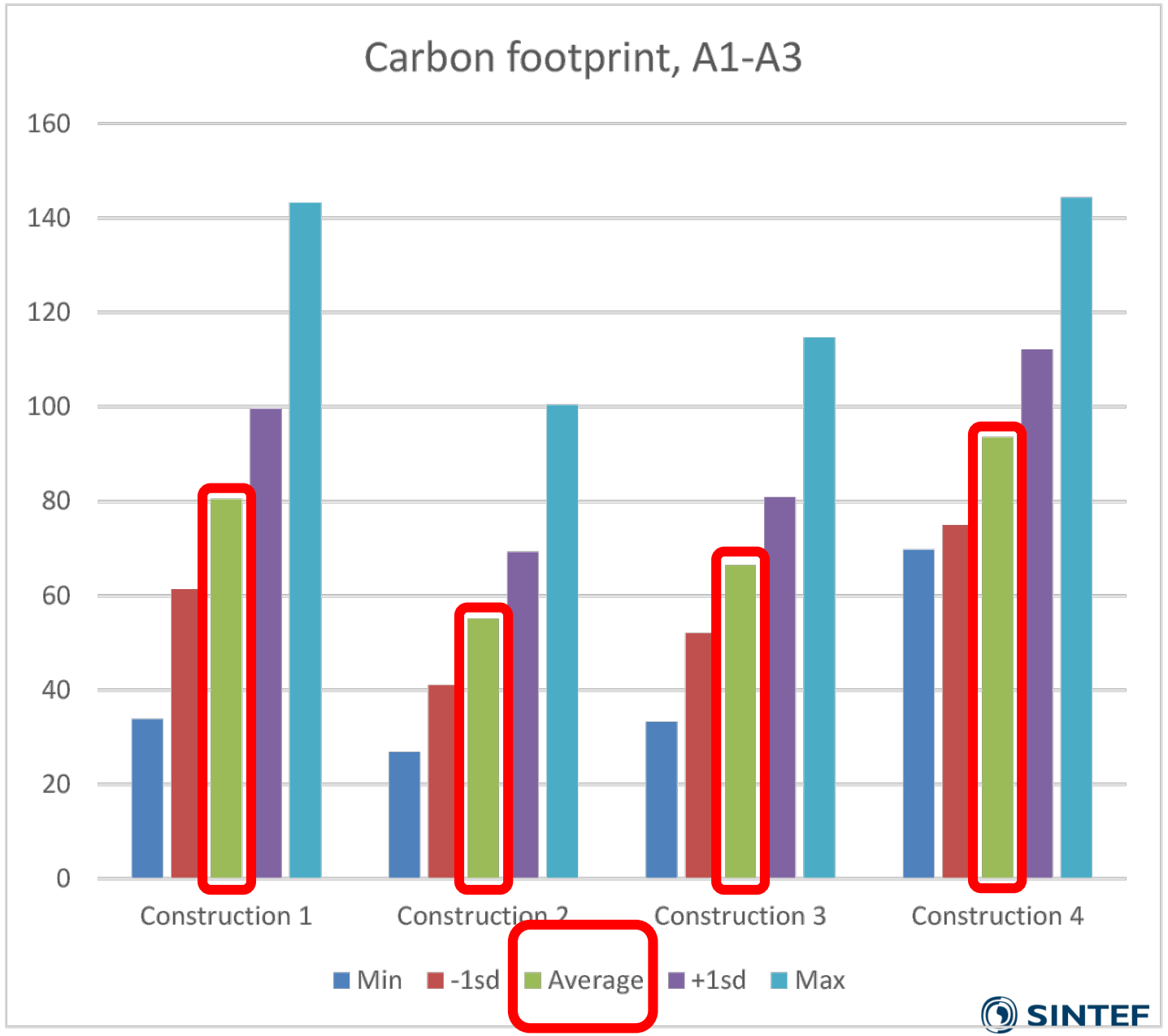



3: Laminated veneer lumber (LVL)




4: Hollow core concrete



# Conclusion and recommendations

- A life cycle perspective is required
- Functional thinking is required
- All comparisons must be done in a building context
- There is a large variation in carbon footprint for similar products
- Wood has a high potential for low carbon solutions
- **Good design can lower the carbon footprint**
- **Poor follow-up can increase the carbon footprint**

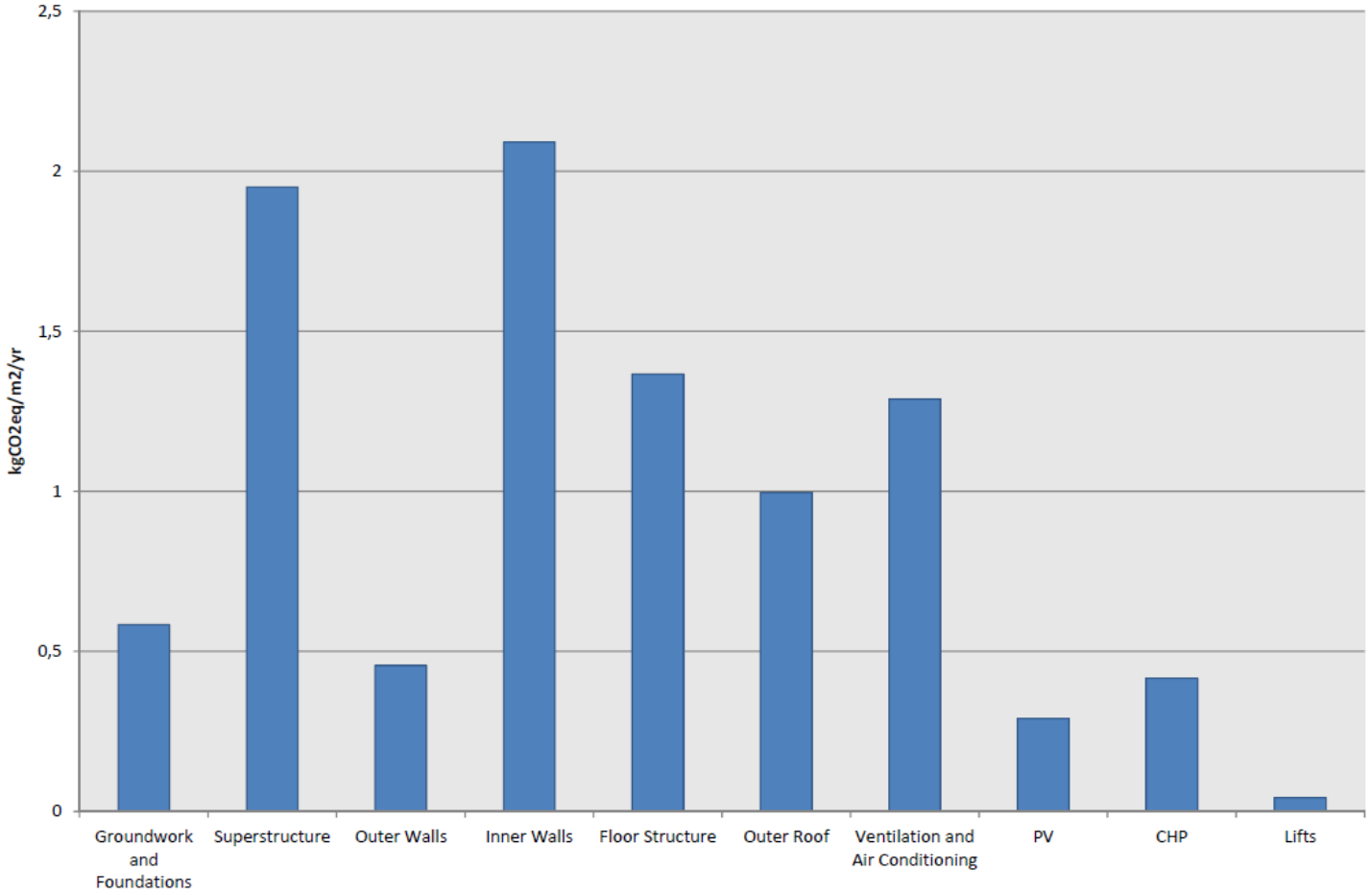
# Examples from Zero Emission Buildings (ZEB)



SINTEF

# Heimdal VGS

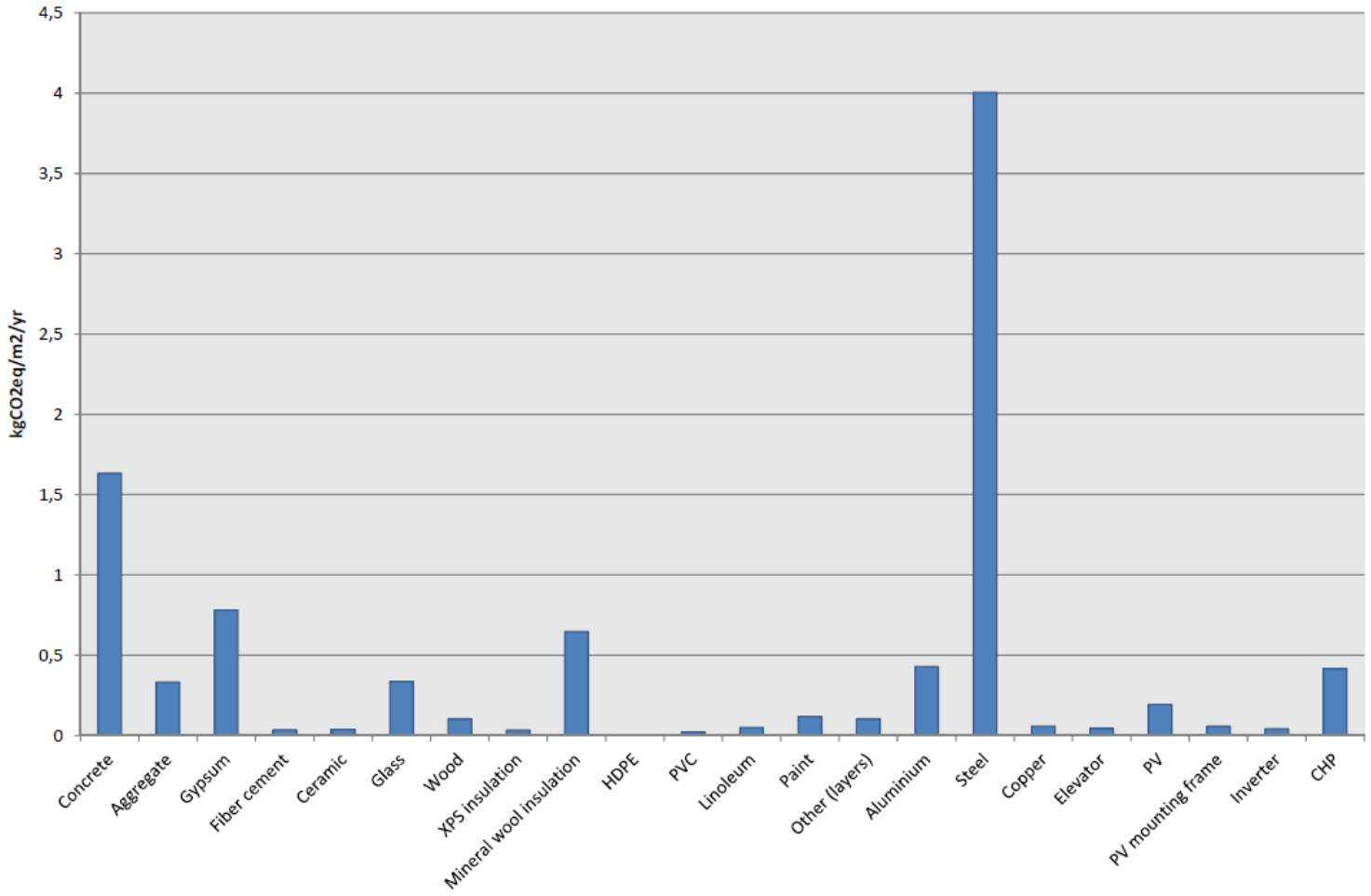
# Carbon footprint per building component






SINTEF

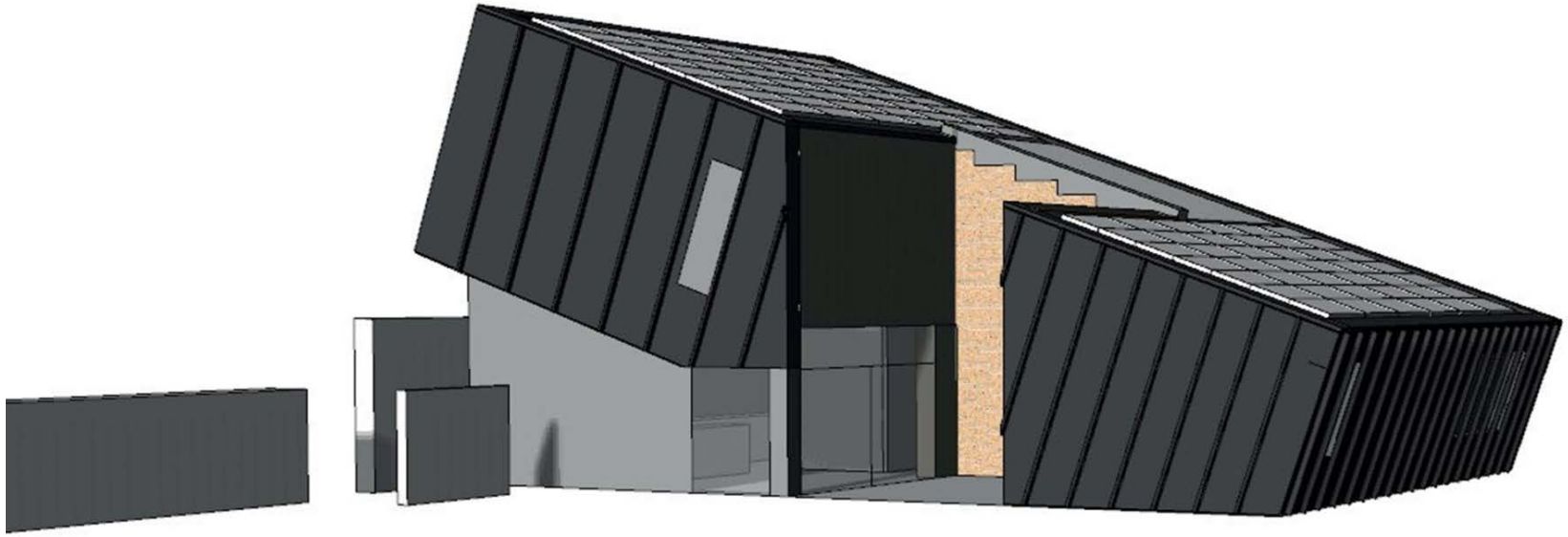
# Carbon footprint per material





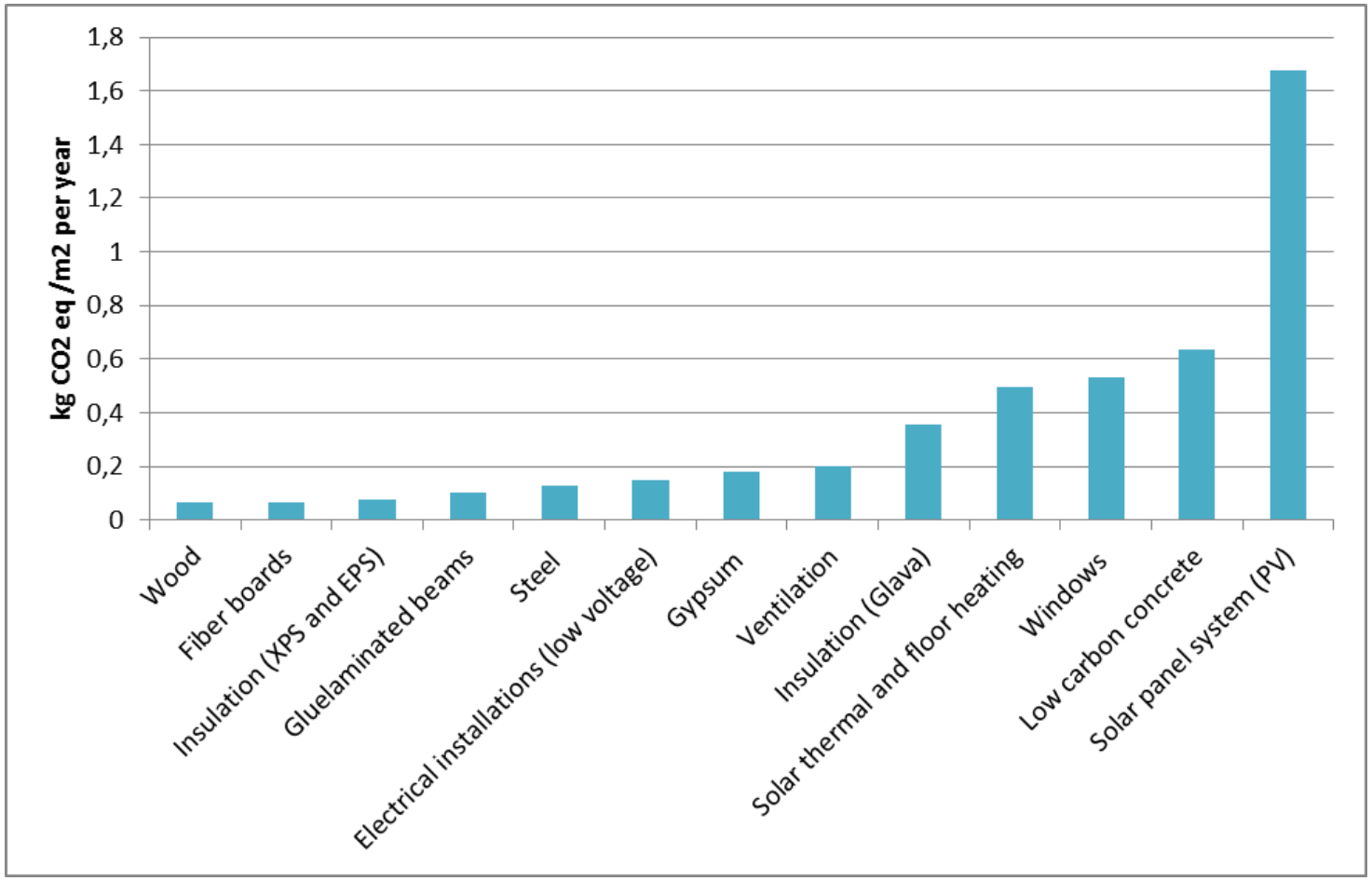

SINTEF

# Multikomforthuset in Larvik



Drawing: Courtesy of Snøhetta

# Multikomforthuset in Larvik

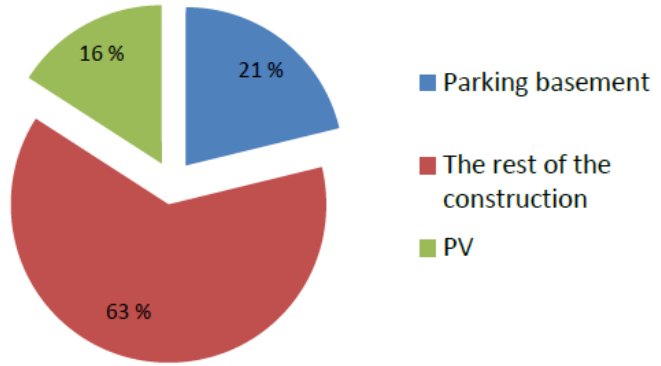


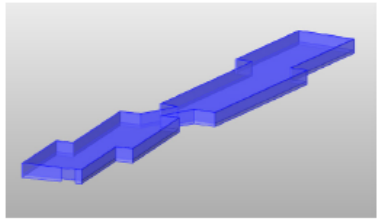

SINTEF

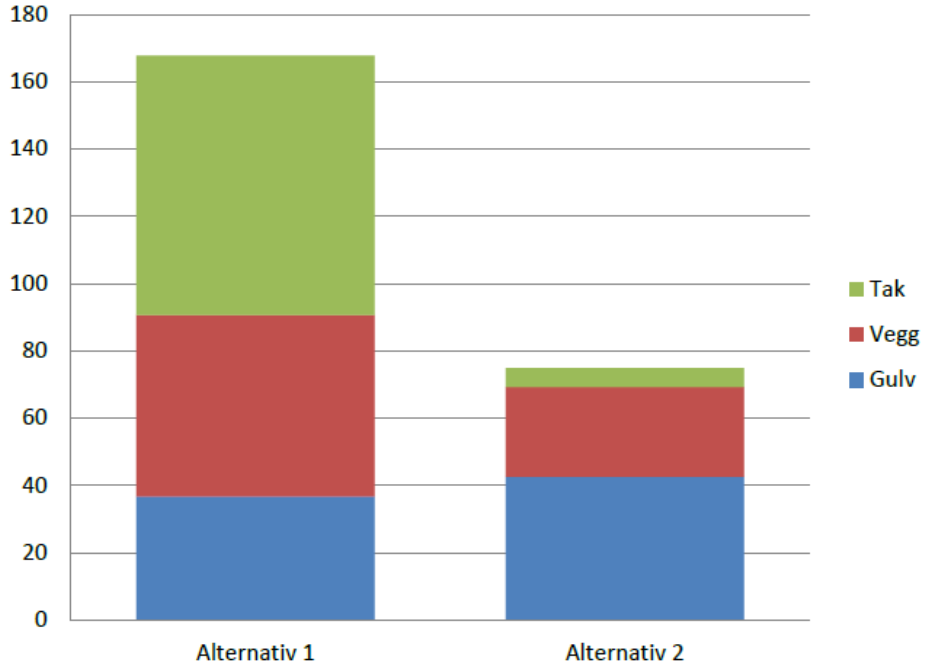
# Zero Village Bergen

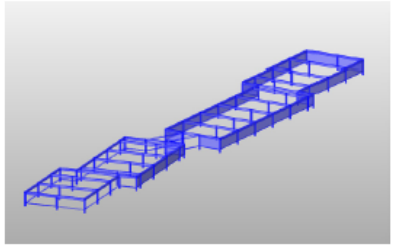
# Carbon footprint, 1m$^2$ roof, 1m$^2$ wall and 1m$^2$ floor

- Optimising parking basement







SINTEF

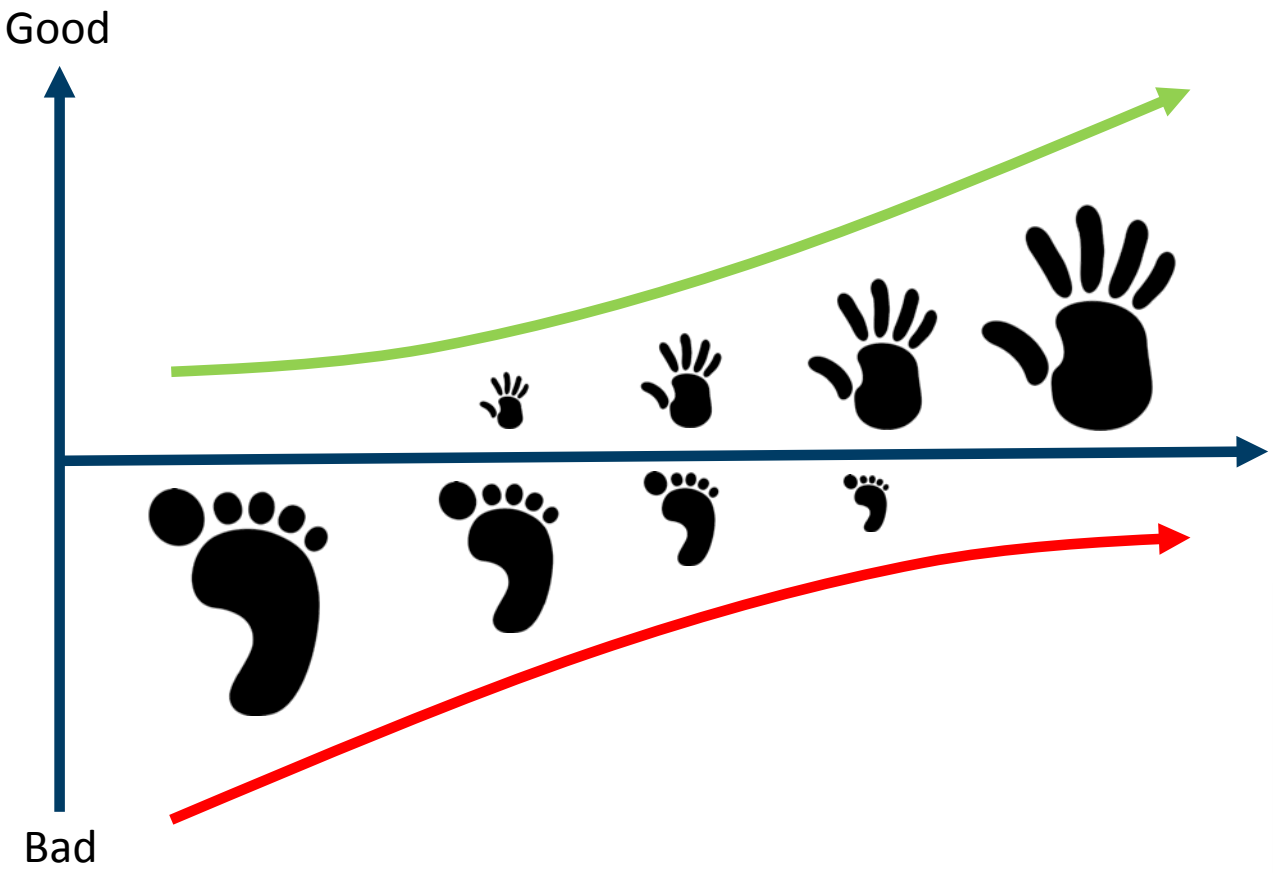
# Summary

# Summary

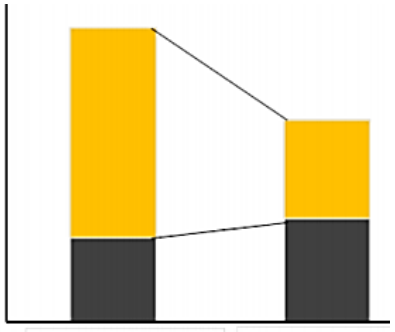
- $CO_2$ emissions and buildings must be seen in context:
  - Of sustainability
  - Of environmental management
  - Of the building
- Life cycle assessment is the basis for carbon footprints
  - Four stages
  - Functional thinking
  - System boundaries
- Carbon footprint calculations for buildings are (typcially) based on ISO and EN standards

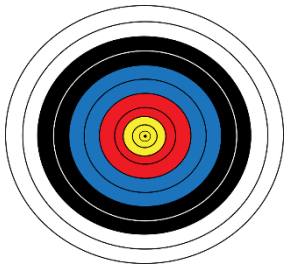
- Finally…

We must reduce the carbon footprint and build good, healthy and sustainable buildings!









SINTEF

SINTEF

Teknologi for et bedre samfunn