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DDI8003 – Week 1

Introduction to life cycle assessment, Introduction to the course

Manuele Margni

(content produced with contributions from Pr. Guillaume Majeau-Bettez and Dr. Laure Patouillard)

POLYTECHNIQUE MONTRÉAL UQÀM EPFL Hes·so

Contextual information about the course

Whenever possible the course will be taught in a dual-mode: face-to-face and broadcasted via an online platform.

The Moodle online platform is used as a repository of course documents.

The courses will also be recorded (whenever possible) so that participants can also follow up in asynchronous mode (on demand only).

The final exam will require a physical presence

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On the agenda today

- Presentation of teachers and students
- Presentation of the syllabus
- Introduction to the LCA project
- Why LCA?
- High level introduction, familiarisation with the concept of life cycle
- Concluding remarks

International Research Consortium on LCA and Sustainable Transition

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https://ciraig.org/index.php/international-research-consortium/

Partners involved:

L'ORÉAL GROUPE
OPTEL
Hydro Québec
SOLVAY
MICHELIN
OCP
ArcelorMittal
LVMH
Québec Ministère de l'Économie, de l'Innovation et de l'Énergie
RICHEMONT
TotalEnergies

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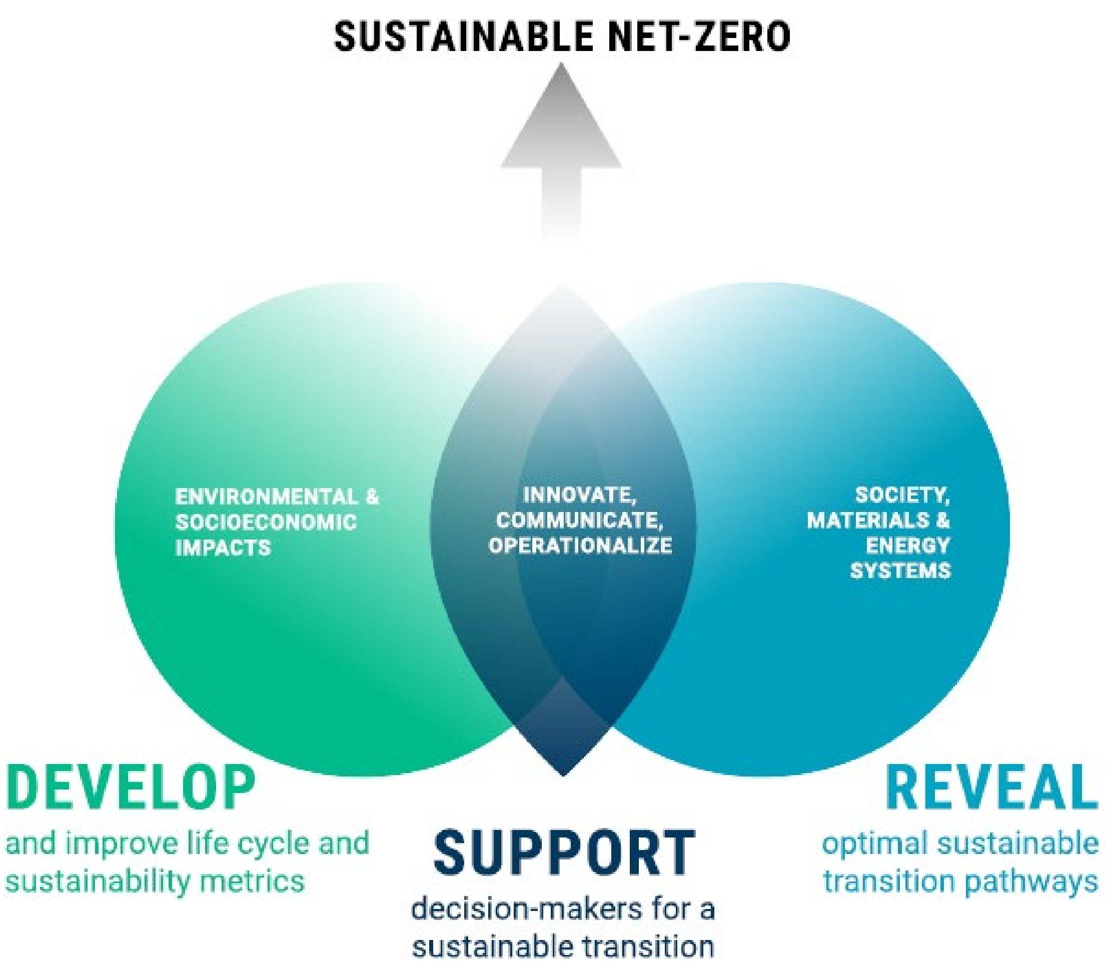
CIRAIG consortium: Five years research program started in 2022



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Professors / teachers

- **Manuele Margni,** Prof. HES-SO Valais, Polytechnique Montréal, CIRAIG, academic guest EPFL
- Life cycle assessment and sustainability metrics
- Co-responsible of the course

- **François Maréchal,** Prof. EPFL, IPESE
- Process and Energy Systems Engineering
- Co-responsible of the course

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Note on the teaching team




- **Soline Corre**
  PhD student at EPFL VS (IPESE)
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- **Dareen Dardor**
  PhD student at EPFL VS (IPESE) & HES-SO Valais Wallis
  dareen.Dardor@epfl.ch

- **Gabriel Magnaval**
  PhD student at Polytechnique Montreal & HES-SO Valais Wallis
  gabriel.magnaval@epfl.ch

- **Sanjay.Venkatachalam**
  PhD student at EPFL Valais (LFIM)
  sanjay.venkatachalam@epfl.ch

Support from additional coaches for the LCA project:

Dr. Eleonora Crenna, Dr. Jocelyn Roth, Dr. Wen Du, MSc David Zenhäusern

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Syllabus

GENERAL OBJECTIVES of the course (summary – complete list in the syllabus)

- Gather a theoretical understanding of LCA
- Analyze, interpret and criticize results of an LCA
- Perform an LCA from A to Z

Pedagogical organisation of the course

- Lectures on LCA theory
- Labs (calculations using LCA software & databases and by hand)
- LCA project performed in a team of students

Syllabus

See the course plan on Moodle

Syllabus – Learning assessment

LCA PROJECT = 50%

PRELIMINARY DELIVRABLE: Oral & Report (10%)

FINAL DELIVRABLE: Oral & Report (40%)

IMPORTANT: The overall evaluation of the LCA project by the teaching team will be tailored to each team member based on peer evaluation (from team members)

FINAL EXAM = 50%

IMPORTANT: A minimum grade of 3.5 over 6 is required in the final exam, otherwise, the grades for the project will not be considered and a failing grade is assigned

Readings

NORME INTERNATIONALE

ISO 14040

Deuxième édition
2006-07-01

Management environnemental — Analyse du cycle de vie — Principes et cadre

Environmental management — Life cycle assessment — Principles and framework

NORME INTERNATIONALE

ISO 14044

Première édition
2006-07-01

Management environnemental — Analyse du cycle de vie — Exigences et lignes directrices

Environmental management — Life cycle assessment — Requirements and guidelines

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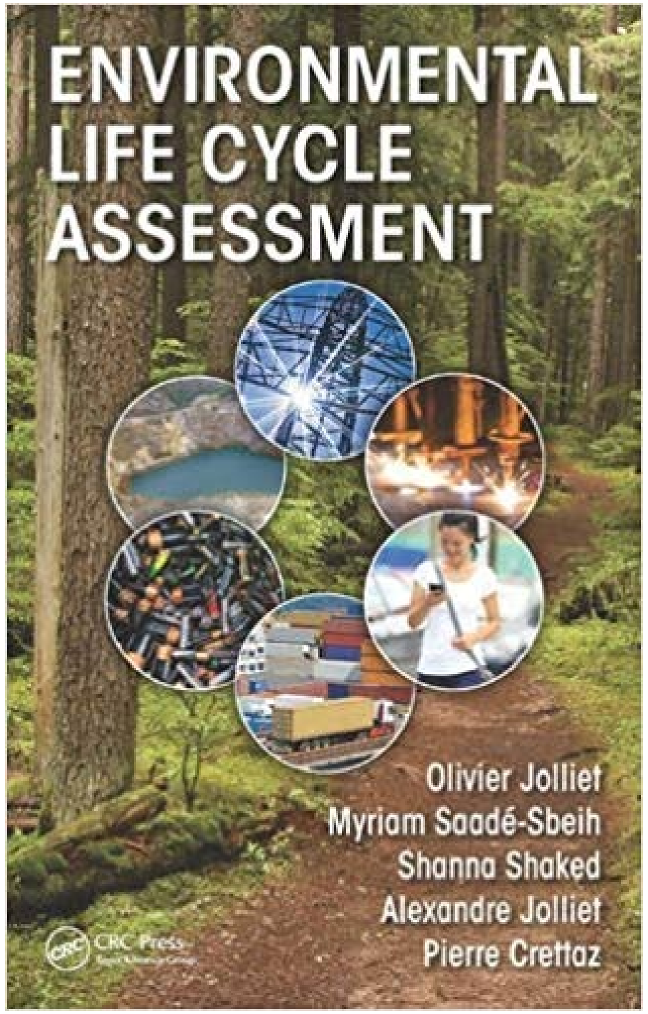
LCA textbooks



Freely available at: https://doi.org/10.1201/b19138

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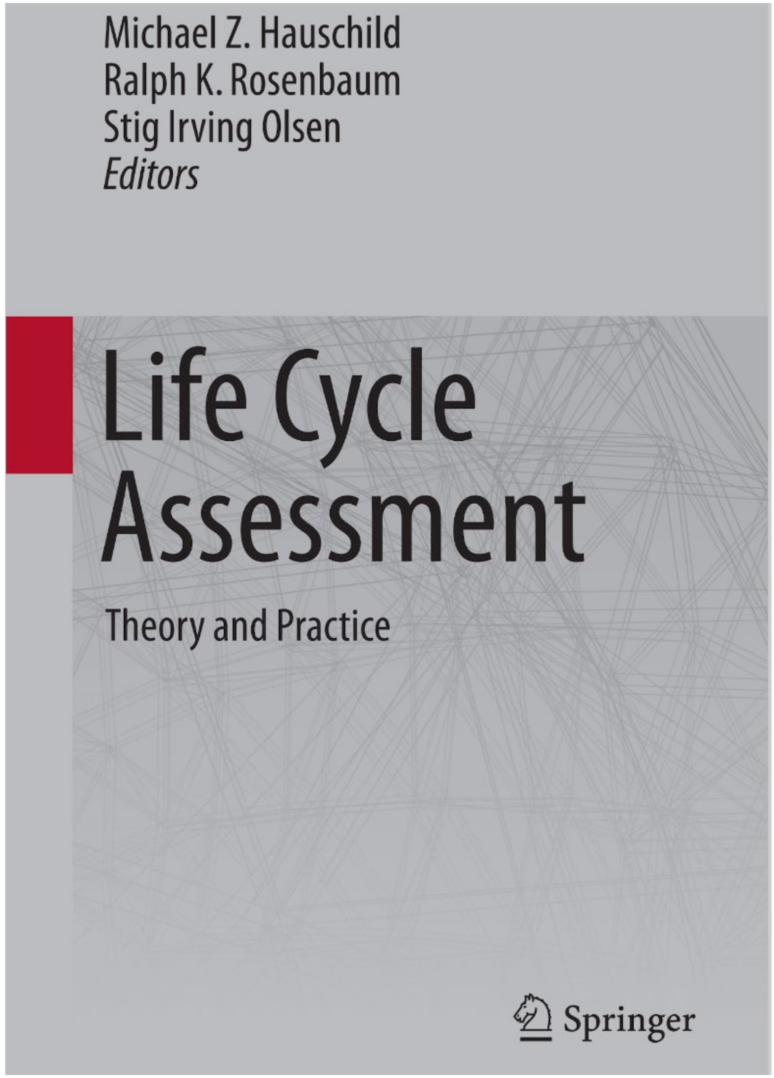
LCA textbooks



Freely available at:
https://link.springer.com/book/10.1007/978-3-319-56475-3

MOOC: introduction à l’analyse du cycle de vie

https://www.edx.org/course/cycle-de-vie

Tools

LCA Software: OpenLCA (http://openlca.org/)

Life cycle inventory database: ecoinvent v3.6

Communication tool / document transfer: Moodle

Zoom for video lectures (whenever possible)

Support

Questions? Doubts?

Step 1: Ask the question to your colleagues on Moodle Forum (we also answer)

Step 2: Teaching assistants by appointment

Step 3: Teachers

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Show how the DDI8003E is organized on Moodle

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LCA Project

- Most important part of the course
- Perform an LCA from A to Z
- Teams of 4-5 students → 11-12 teams MAX
- It’s possible that we force members into teams

Choosing the subject of your LCA project

- Comparison of products / services
- Prioritize subjects…
  - **That you are passionate about**
  - **For which you have access to data**
  - **Within a clear context**
  - **That are important to you and on which you already have some knowledge**
- Avoid subjects…
  - **With obvious conclusions**
  - **That were already studied many times**
  - **That are too complicated or complex**
- We will validate the subjects with you

LCA project

- Groups (4-5 students) shall be formed and project proposals approved by the end of the course on week 3.

- Submit your project proposal:
  - **Register your project in the « LCA project » section of Moodle** **"Registation of LCA group projects"**
  - **Ask teachers to validate the project and the group**

- Use course breaks and Moodle forum
  - **to select and create a group / suggest a project topic**

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Going beyond environmental intuition

PART 1

Our intuition: zero waste

Wrapped or no?

creates food waste

creates plastic waste

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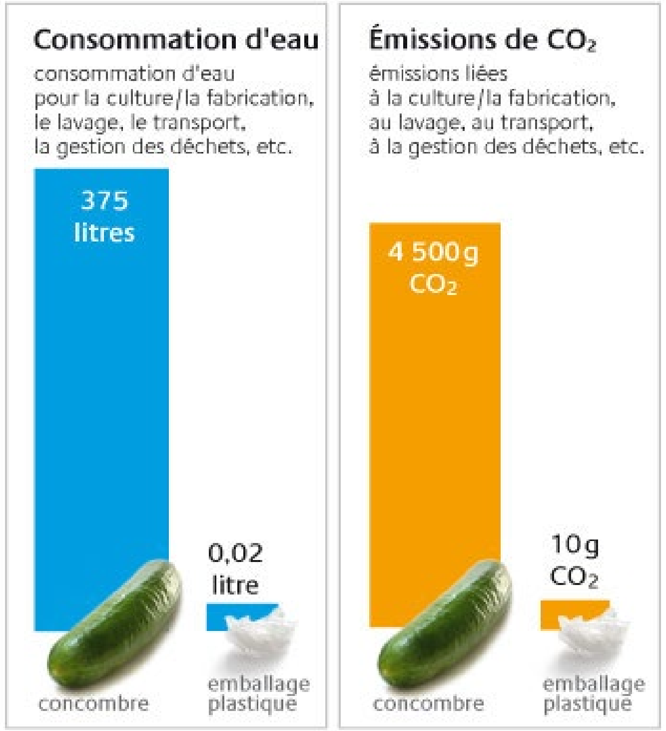
Our intuition: zero waste

Why are cucumbers wrap in plastic?



http://www.letstalkplastics.com/fr/facts/a-t-on-vraiment-besoin-d-emballer-les-concombres-dans-du-plastique

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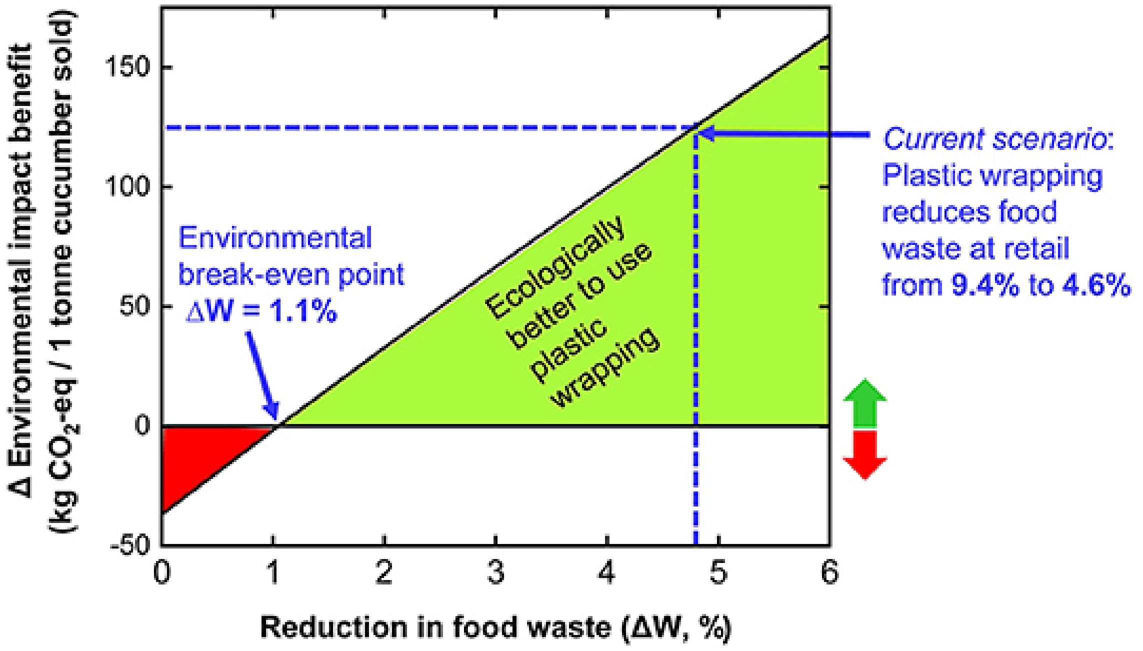
Our intuition: zero waste

Why are cucumbers wrap in plastic?



https://www.frontiersin.org/articles/10.3389/fsufs.2022.750199/full

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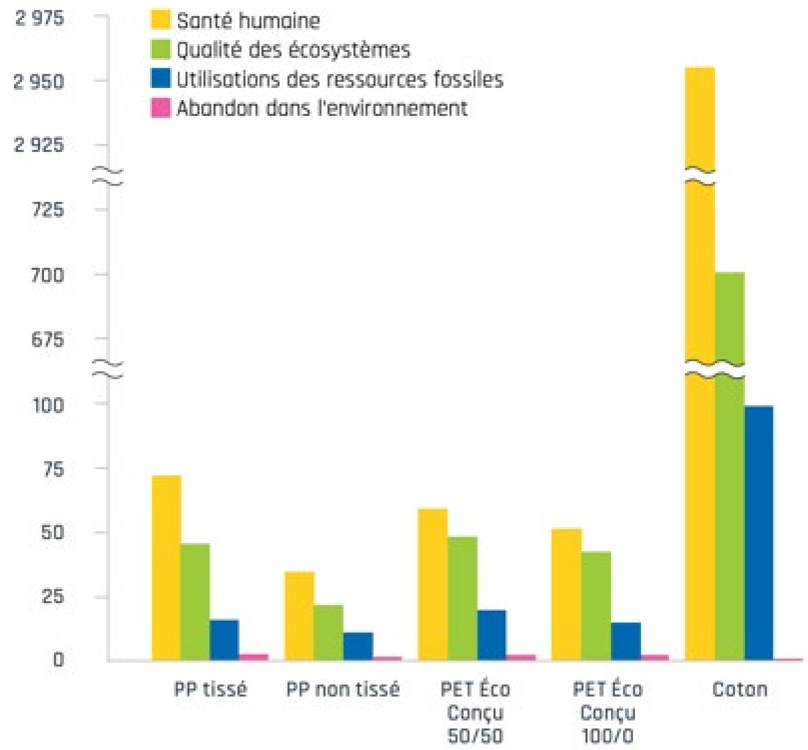
Our intuition: no single use

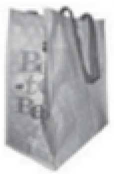
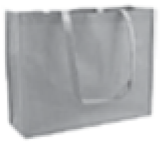
Banning single-use grocery bags?

	Plastique conventionnel	▪ Polyéthylène haute densité (HDPE) ▪ Plastique # 2 ▪ À bretelles ▪ 17 microns ▪ Fabriqué au Canada

Number of use to be equivalent to single-use bag

(En nombre d'utilisation équivalent au sac de plastique conventionnel)

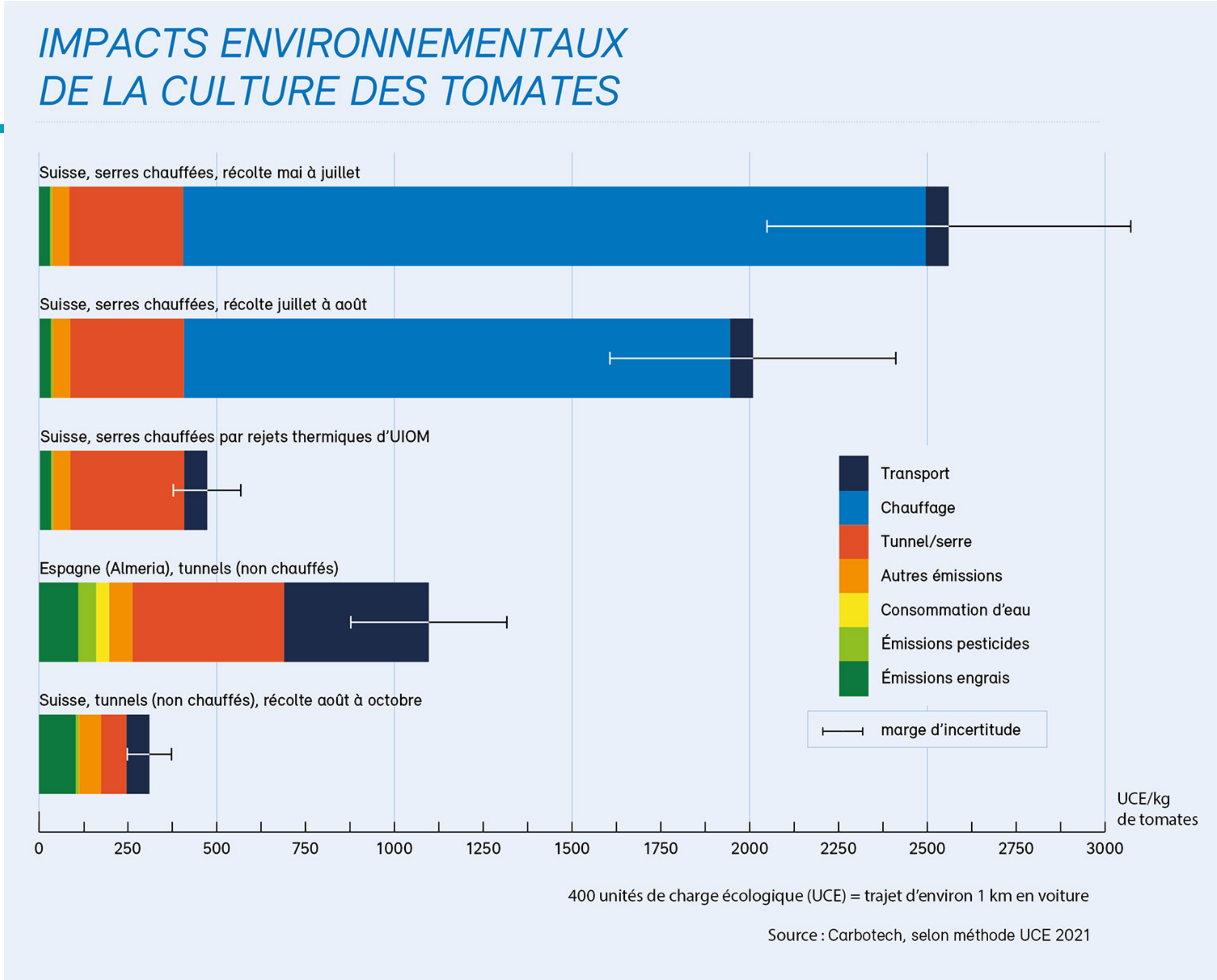


	PP tissé	▪ Polypropylène (PP) ▪ Plastique # 5 ▪ Fabriqué en Chine
	PP non tissé	▪ Polypropylène (PP) ▪ Plastique # 5 ▪ Fabriqué en Chine ▪ Fait à 100 % en plastique recyclé postconsommation
	Coton	▪ Fabriqué en Chine
	Sac écoconçu (sac Credo)	▪ Polyéthylène (PE) ▪ Plastique # 1 ▪ Fabriqué au Québec (à Montréal) ▪ Fait à 100 % en contenu recyclé

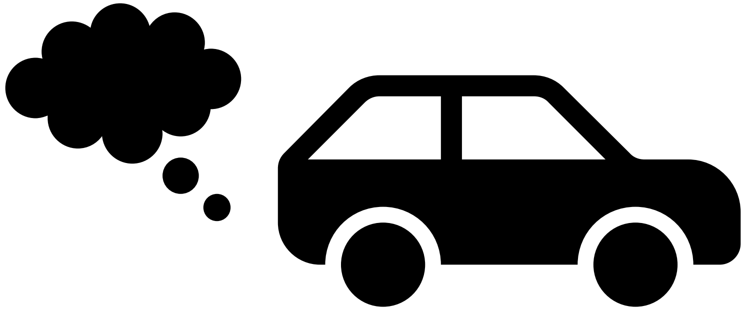
https://www.recyc-quebec.gouv.qc.ca/sites/default/files/documents/acv-sacs-emplettes-faits-saillants.pdf

Our intuition: buy local

… or/and seasonal?

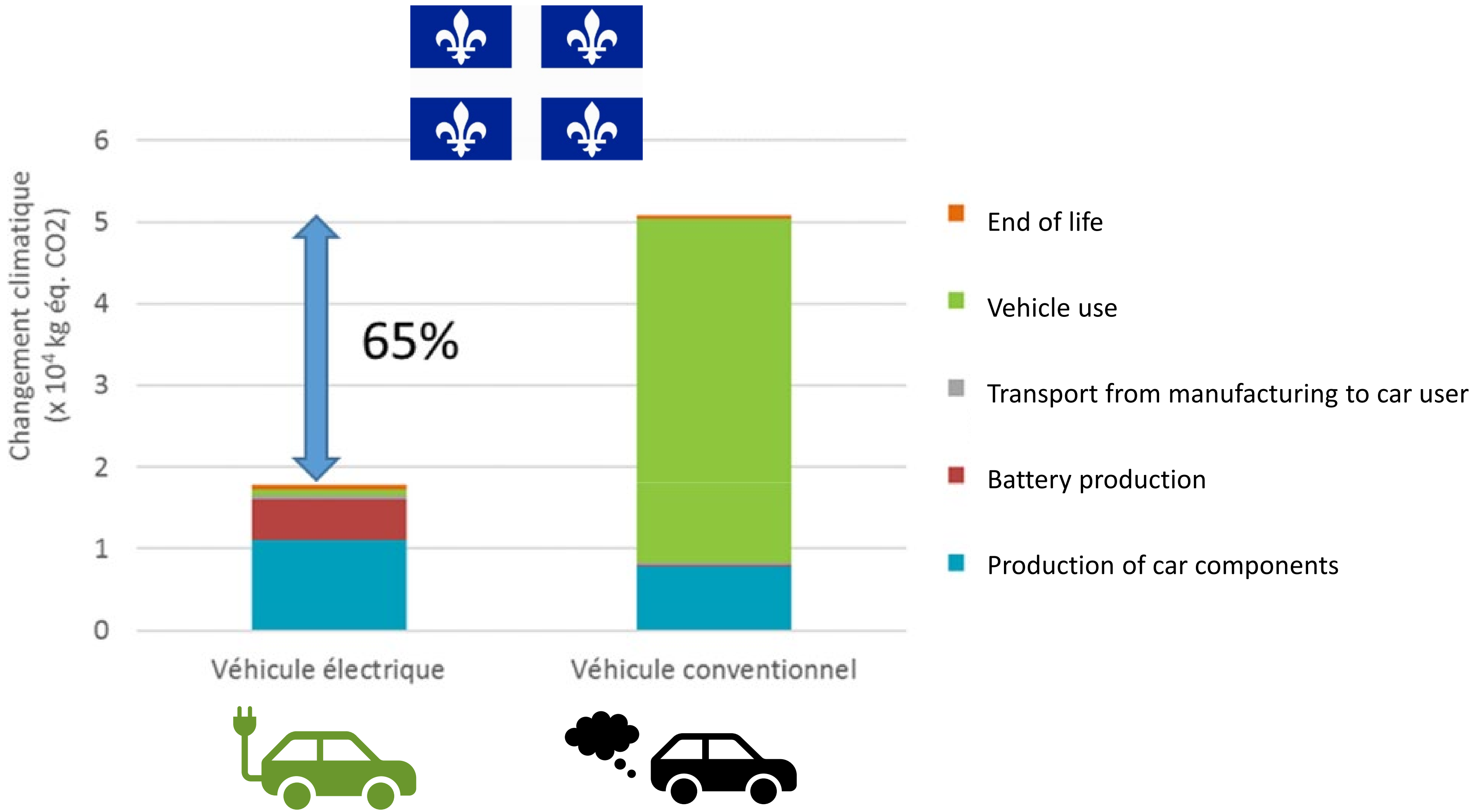


Our intuition: zero emission



Our intuition: zero emission

Climate change



For 150,000 km (Functional unit)

(CIRAIG, 2016; http://www.hydroquebec.com/developpement-durable/centre-documentation/acv-vehicule-electrique.html2016)

Comparison electric vs. conventional car in Québec

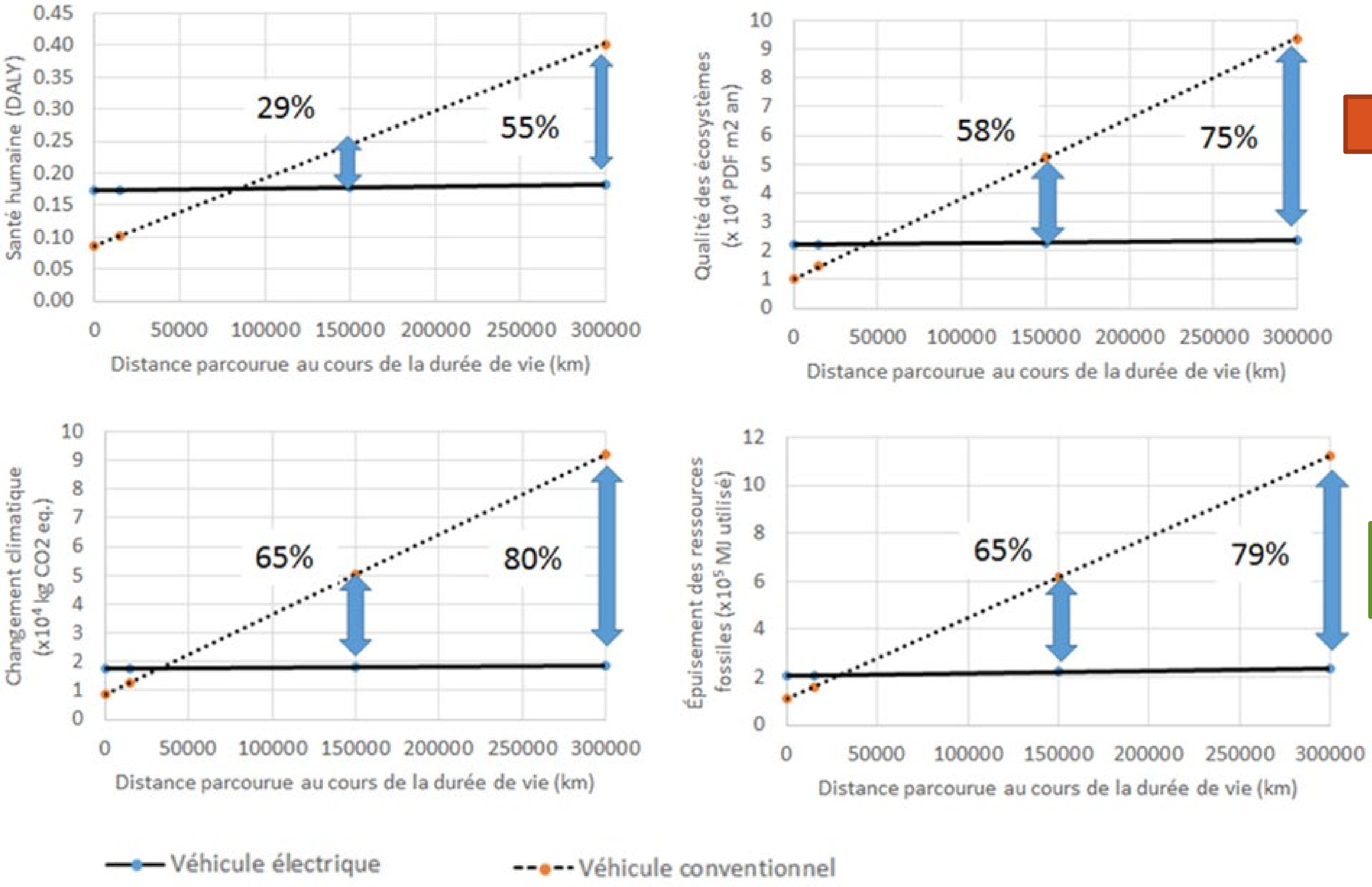
Human health

Ecosystem Quality

Climate change

Depletion of fossil resources

as a function of distance



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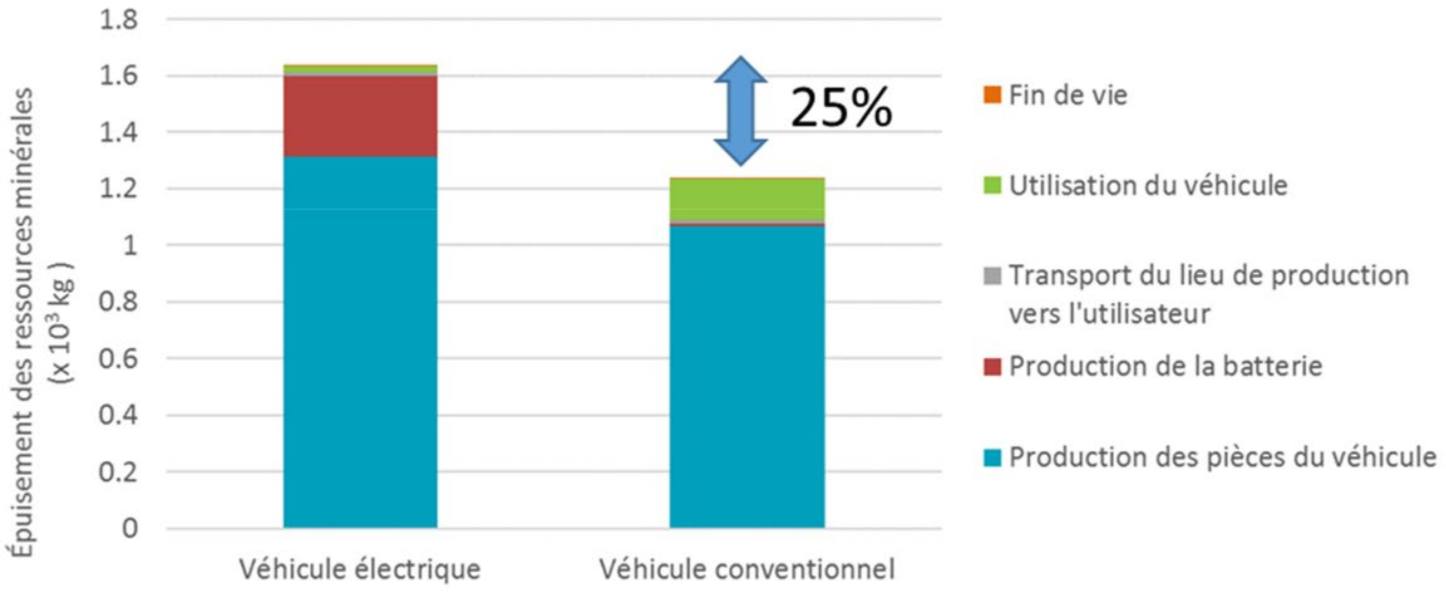
(CIRAIG, 2016; http://www.hydroquebec.com/developpement-durable/centre-documentation/acv-vehicule-electrique.html2016)

Comparison electric vs. conventional car in Québec

Trends are reversed for the indicator « depletion of mineral resources»



(CIRAIG, 2016)

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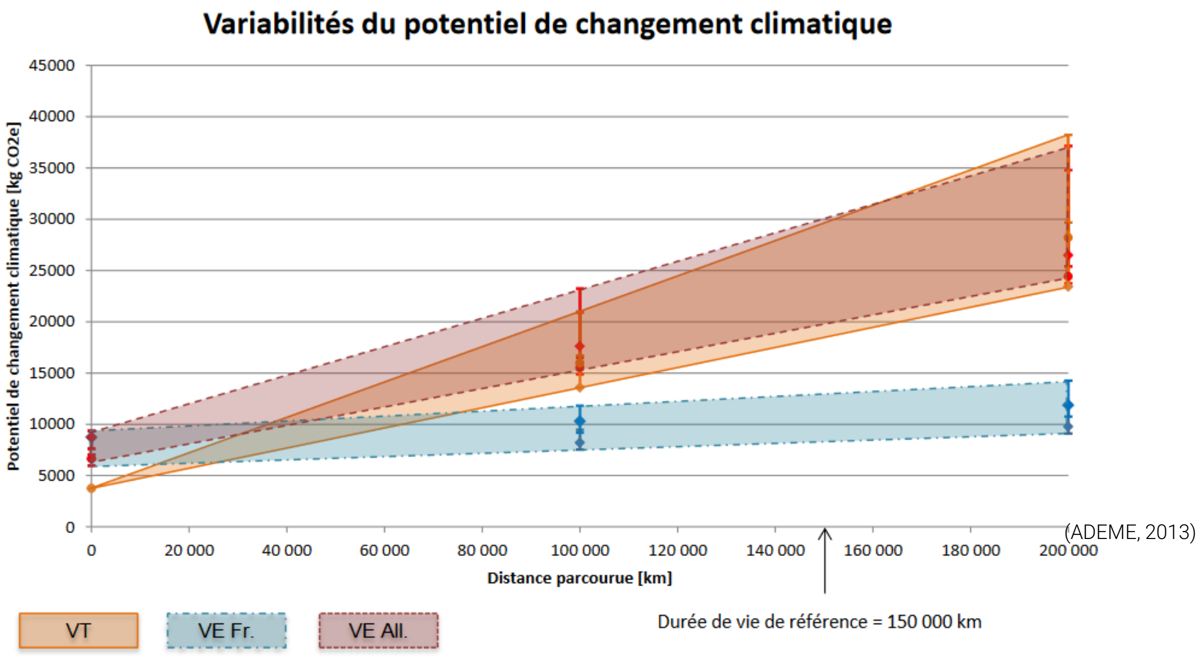
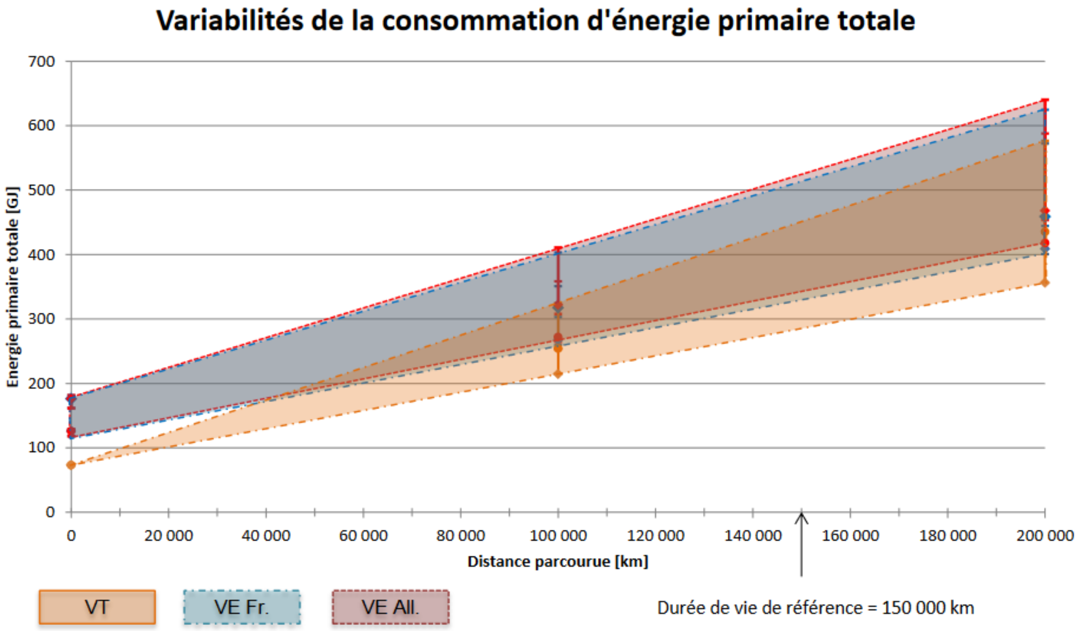
Electric vehicles vs conventional vehicles in other context: France and Germany

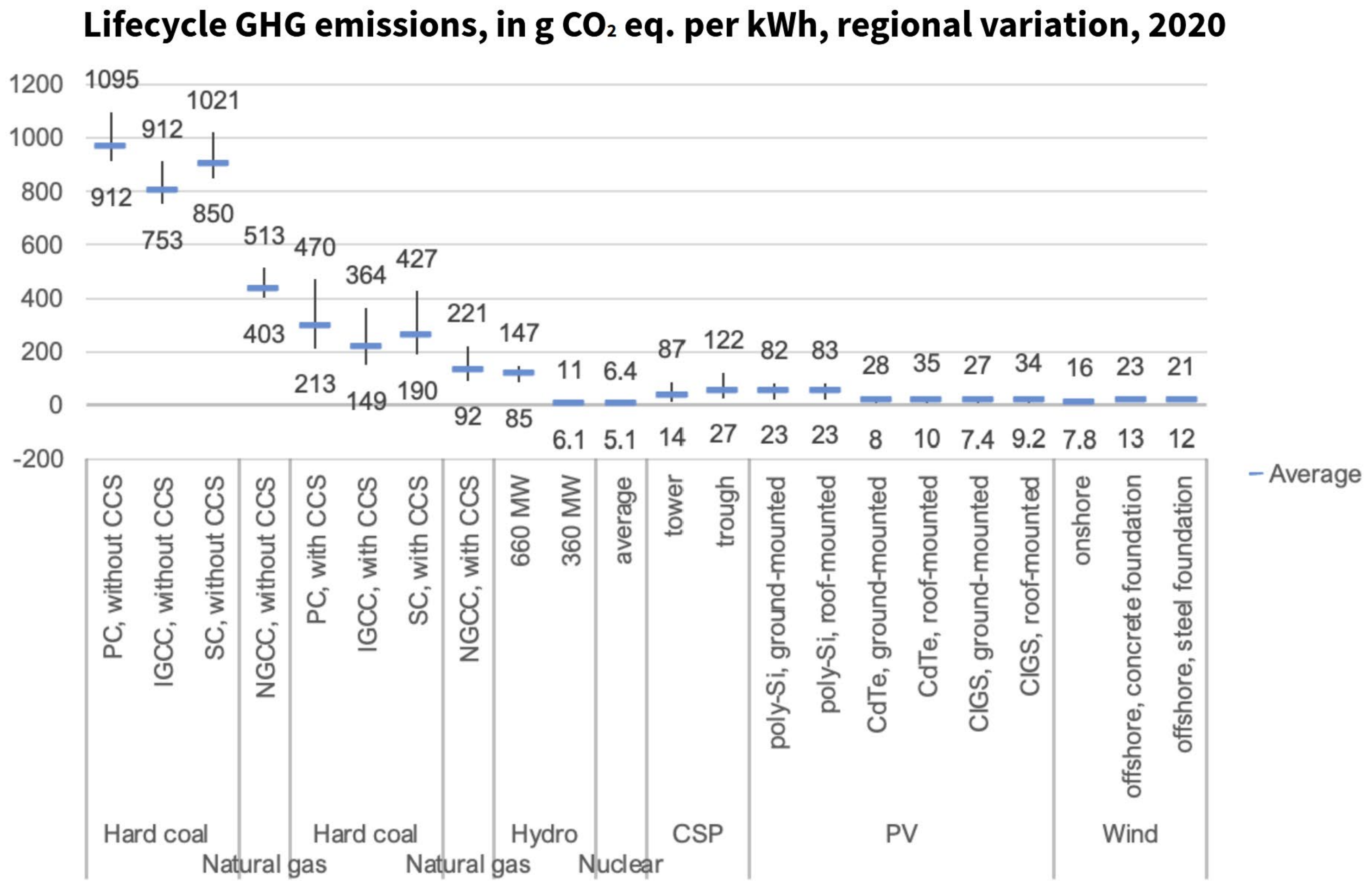


Conventional vehicle

Electric vehicle



LCA of electricity production



Uited Nations (2022). Carbon Neutrality in the UNECE Region: Integrated Life-cycle Assessment of Electricity Sources, Geneva.
https://unece.org/sites/default/files/2022-04/LCA_3_FINAL%20March%202022.pdf

Why is LCA useful in sustainable production & consumption?

It helps with decision-making to reduce environmental impacts

It allows us to go beyond our intuition and « rules of thumb »

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Why take a « life cycle » approach?

PART 2

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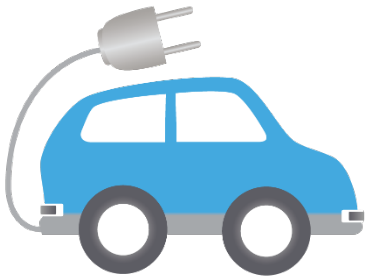
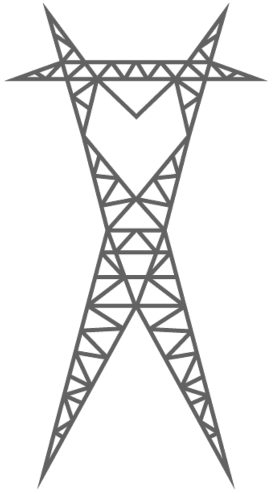
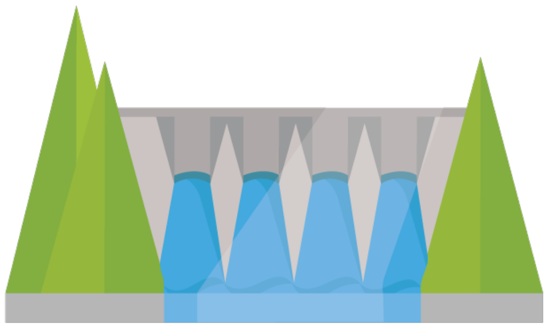
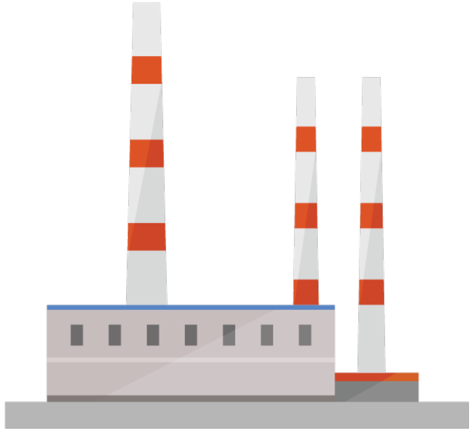
Need for a life cycle perspective

Zero emissions?

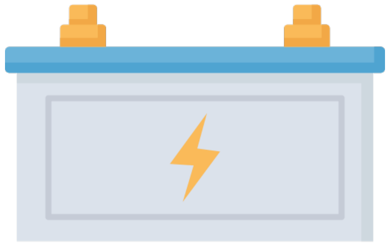


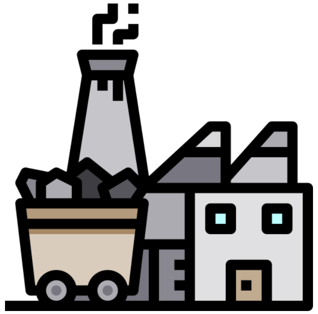






Or emissions elswere?





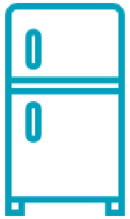
Need to assess several environmental impacts

The balance of an ecosystem depends on the health of all its parts
(not only climate change)

Avoid burden shift from one environmental issue to another

<u>Example of refrigeration systems</u>

Chlorométhane,
Sulfur dioxide,
Ammonia

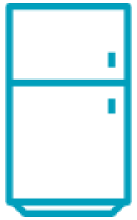


Toxicity

1950 →

Created by HeadsOfBirds
from Noun Project

CFC

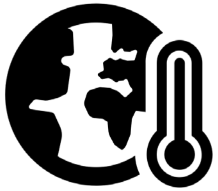


Toxicity

Ozone depletion

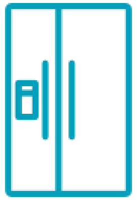
1987 →

1 kg of HCFC corresponds to 10 000 kg of CO_2



Created by Adrien Coquet
from Noun Project

HCFC



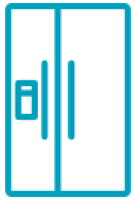
Climate change

Ozone depletion

2010's →

1 kg of HFC (R134a) corresponds to 1 550 kg of CO_2

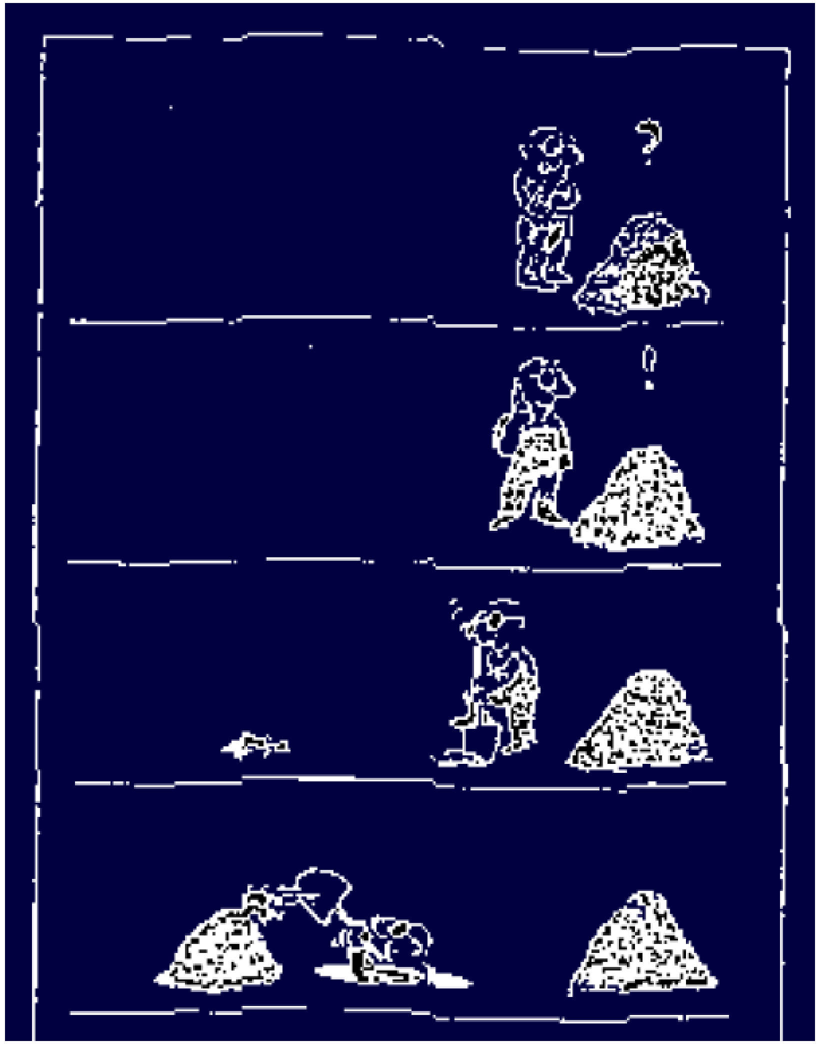
HFC

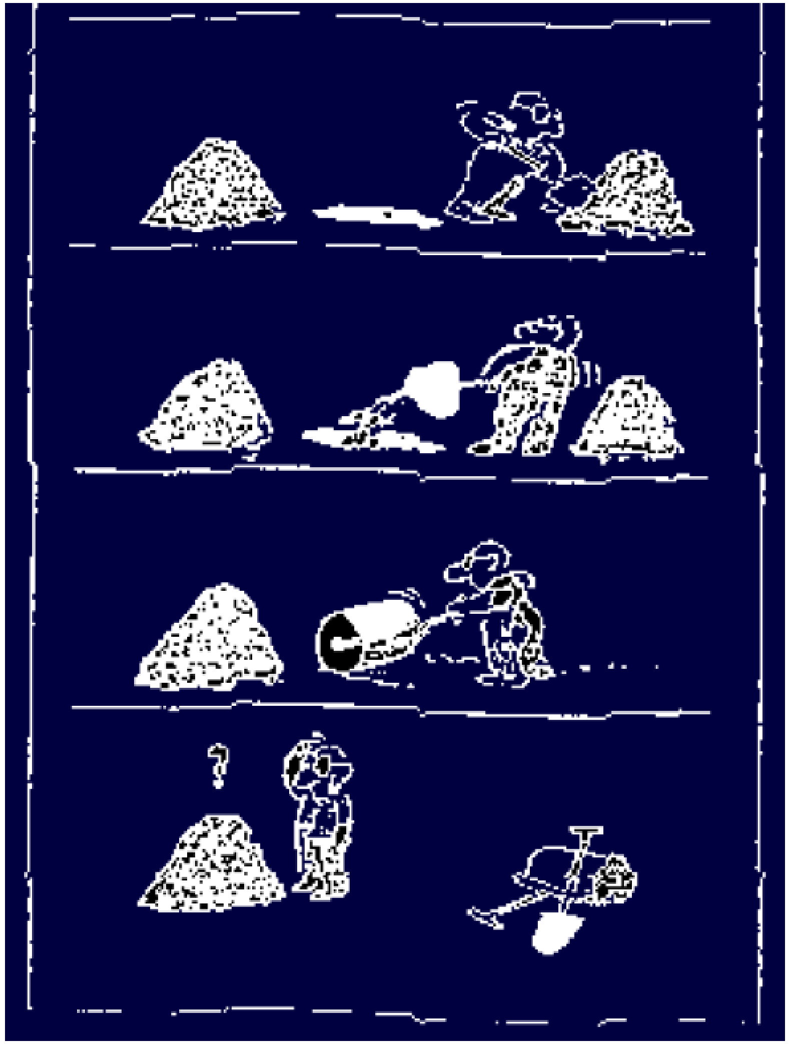


Climate change

Ozone depletion

Avoid burden shift → Don't put off the problem!





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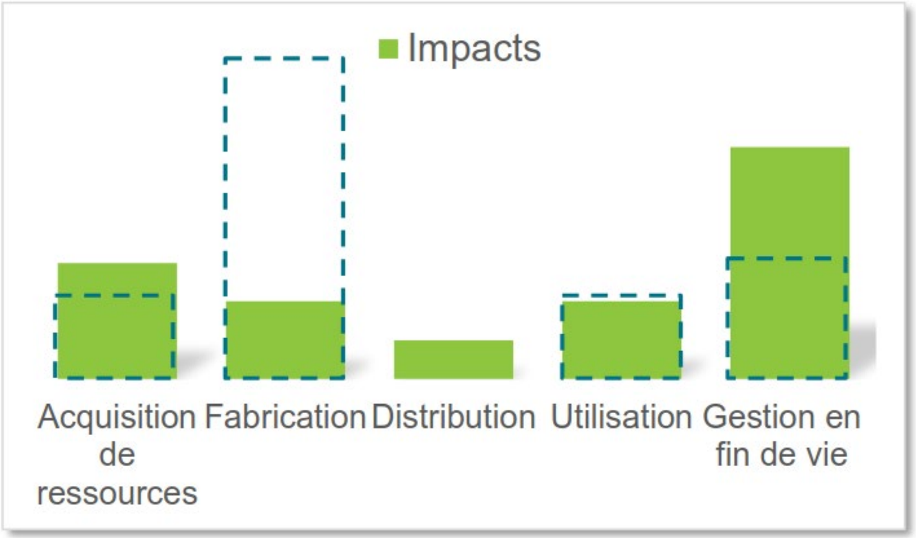
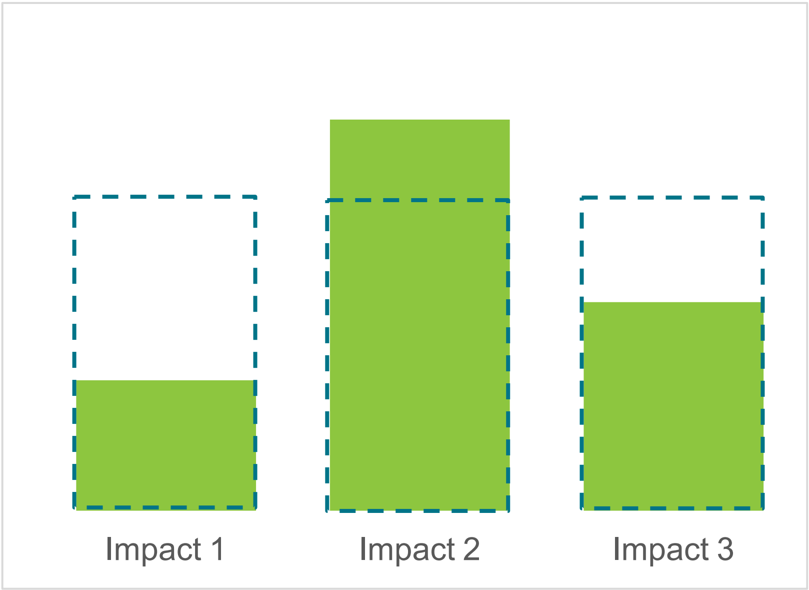
LCA is based on 2 principles to avoid burden shift

1st principle =
Life cycle approach



2nd principle =
Multi-indicator approach



Impacts before

Impacts after

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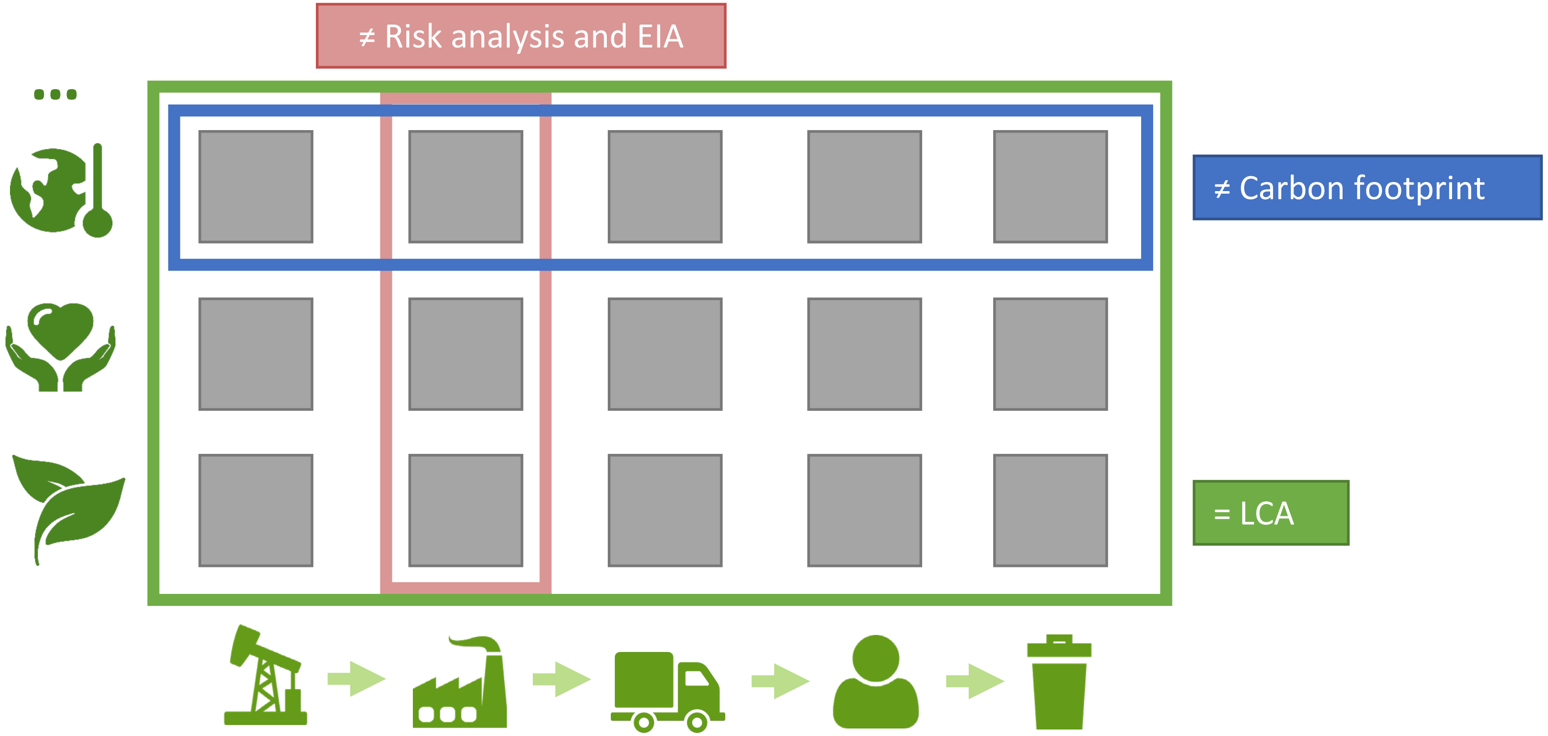
Provide an example of burden shift

Across life cycle stages?

Between environmental problems?

LCA vs. other environmental assessment tools

Life cycle assessment (LCA) = methodology to ***quantify*** *all the potential environmental* ***impacts*** *of a product or a service all along its* ***life cycle***



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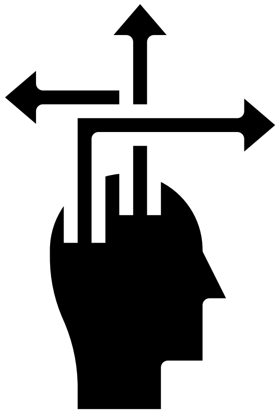
LCA, what is it for?

*LCA is a tool to **inform decision-making** related to environmental aspects*

Explore scenarios



Inform decision-making

- Ecodesign during R&D stage
- Technological choices
- Supplier choices
- Strategic decisions
- Public policies
- Marketing/ Labeling

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What do we do with LCA results?

Identification of « hotspots »

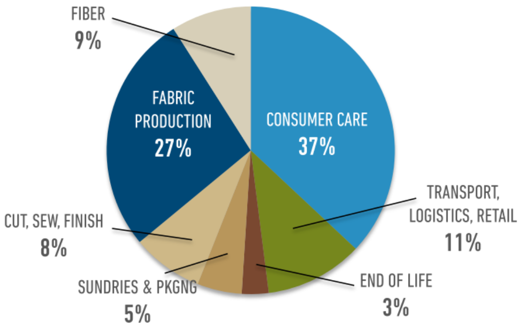
Identification of activities and life cycle stages or environmental issues with the greatest contribution to impacts

http://levistrauss.com/wp-content/uploads/2015/03/Full-LCA-Results-Deck-FINAL.pdf

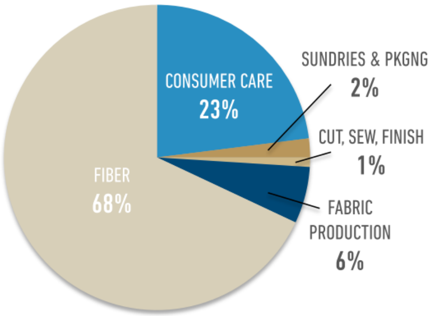
Comparison of products or scenarios

Identification of best or worst options

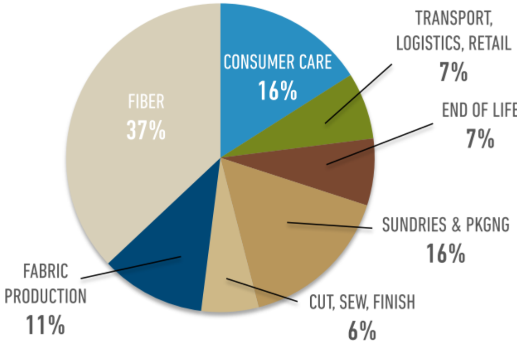
CRADLE TO GRAVE CLIMATE CHANGE IMPACT PERCENTAGE BY PHASE



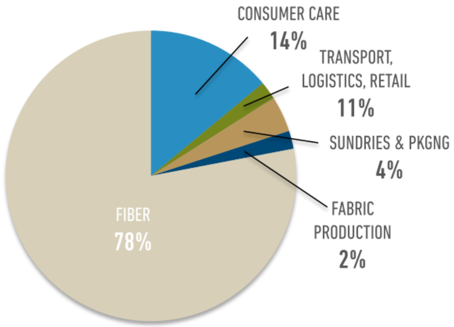
CRADLE TO GRAVE WATER CONSUMPTION PERCENTAGE BY PHASE



CRADLE TO GRAVE EUTROPHICATION PERCENTAGE BY PHASE

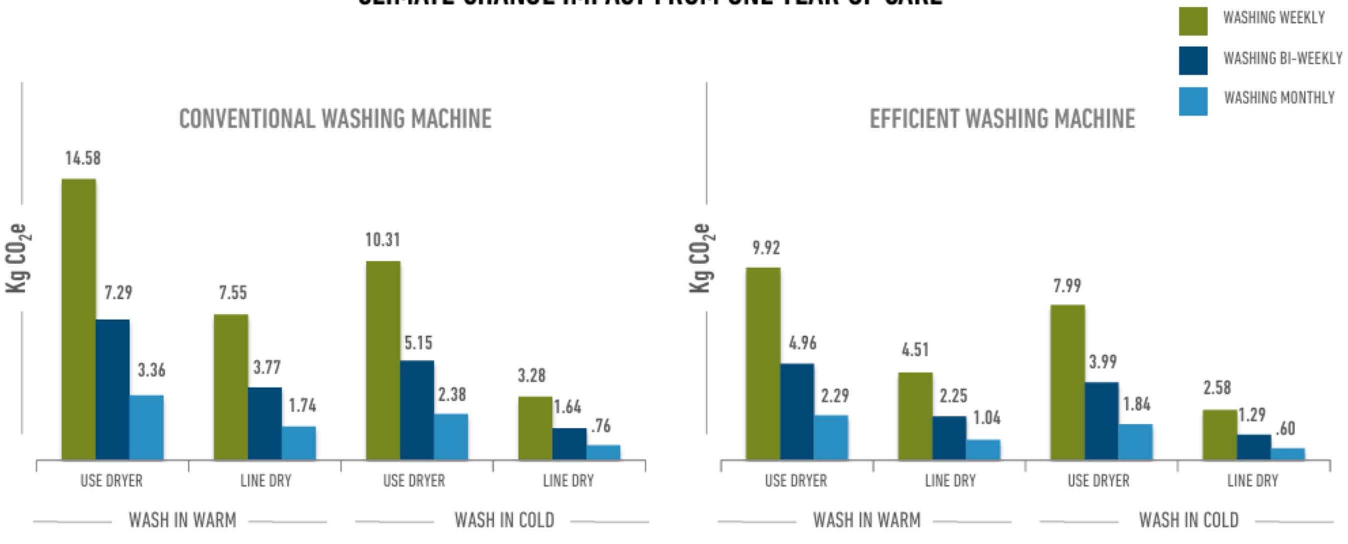


CRADLE TO GRAVE LAND OCCUPATION PERCENTAGE BY PHASE



THE CLIMATE CHANGE IMPACT OF CONSUMERS WASHING AND DRYING THEIR JEANS VARIES GREATLY DEPENDING ON WASHING FREQUENCY, METHODS, AND EQUIPMENT

CLIMATE CHANGE IMPACT FROM ONE YEAR OF CARE



LEVI STRAUSS & CO. © 2015

Note: for one pair of pants worn by the average American consumer

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Eco-design

« Systematic integration of environmental aspects in the design and development of products (goods and services, systems) with the objective of reducing negative environmental impacts throughout their life cycle for equivalent or superior service […] ».

Norme NF X 30-264

A bad example of design

« Nestlé abandons Cailler packaging: […] sales of the redesigned chocolate […] dropped by 31% »

Quotidien Le Temps, 27 January 2007

« The *Consumers' Federation of French-speaking Switzerland notes that they have a five times greater impact on the environment in terms of* CO_2 *when burned* »

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December 2008

Design of a new baby food packaging

Int J Life Cycle Assess
DOI 10.1007/s11367-008-0052-6

CASE STUDY

Life cycle assessment of two baby food packaging alternatives: glass jars vs. plastic pots

Sebastien Humbert · Vincent Rossi · Manuele Margni · Olivier Jolliet · Yves Loerincik

Received: 21 August 2008 / Accepted: 28 November 2008

Abstract

Background, aim, and scope This paper compares the life cycle assessment (LCA) of two packaging alternatives used for baby food produced by Nestlé: plastic pot and glass jar. The study considers the environmental impacts associated with packaging systems used to provide one baby food meal in France, Spain, and Germany in 2007. In addition, alternate logistical scenarios are considered which are independent of the two packaging options. The 200-g packaging size is selected as the basis for this study. Two other packaging sizes are assessed in the sensitivity analysis. Because results are intended to be disclosed to the public, this study underwent a critical review by an external panel of LCA experts.

Materials and methods The LCA is performed in accordance to the international standards ISO 14040 and ISO 14044. The packaging systems include the packaging production, the product assembly, the preservation process, the distribution, and the packaging end-of-life. The production of the content (before preservation process), as well as the use phase are not taken into account as they are considered not to change when changing packaging. The inventory is based on data obtained from the baby food producer and the suppliers, data from the scientific literature, and data from the ecoinvent database. Special care is taken to implement a system expansion approach for end-of-life open and closed loop recycling and energy production (ISO 14044). A comprehensive impact assessment is performed using two life cycle impact assessment methodologies: IMPACT 2002+ and CML 2001. An extensive uncertainty analysis using Monte Carlo as well as an extensive sensitivity study are performed on the inventory and the reference flows, respectively.

Results When looking at the impacts due to preservation process and packaging (considering identical distribution distances), we observe a small but significant environmental benefit of the plastic pot system over the glass jar system. Depending on the country, the impact is reduced by 14% to 27% for primary energy, 28% to 31% for global warming, 31% to 34% for respiratory inorganics, and 28% to 31% for terrestrial acidification/nutrification. The environmental benefit associated with the change in packaging mainly results from (a) production of plastic pot (including its end-of-life; 43% to 51% of total benefit), (b) lighter weight of packaging positively impacting transportation (20% to 35% of total benefit), and (c) new preservation process permitted by the plastic system (23% to 34% of total benefit). The jar or pot (including cap or lid, cluster, stretch film, and label) represents approximately half of the life cycle impacts, the logistics approximately one fourth, and the rest (especially on-site energy, tray, and hood) one fourth.

Discussion The sensitivity analysis shows that assumptions made in the basic scenarios are rather conservative for plastic pots and that the conclusions for the 200-g packaging size also apply to other packaging sizes. The uncertainty analysis performed on the inventory for the German market situation shows that the plastic pot system has less impact than the glass jar system while considering similar distribution distances with a confidence level above 97% for most impact categories. There is opportunity for further improvement independent of the type of packaging used, such as by reducing distribution distances while still optimizing lot size. The validity of the main conclusions

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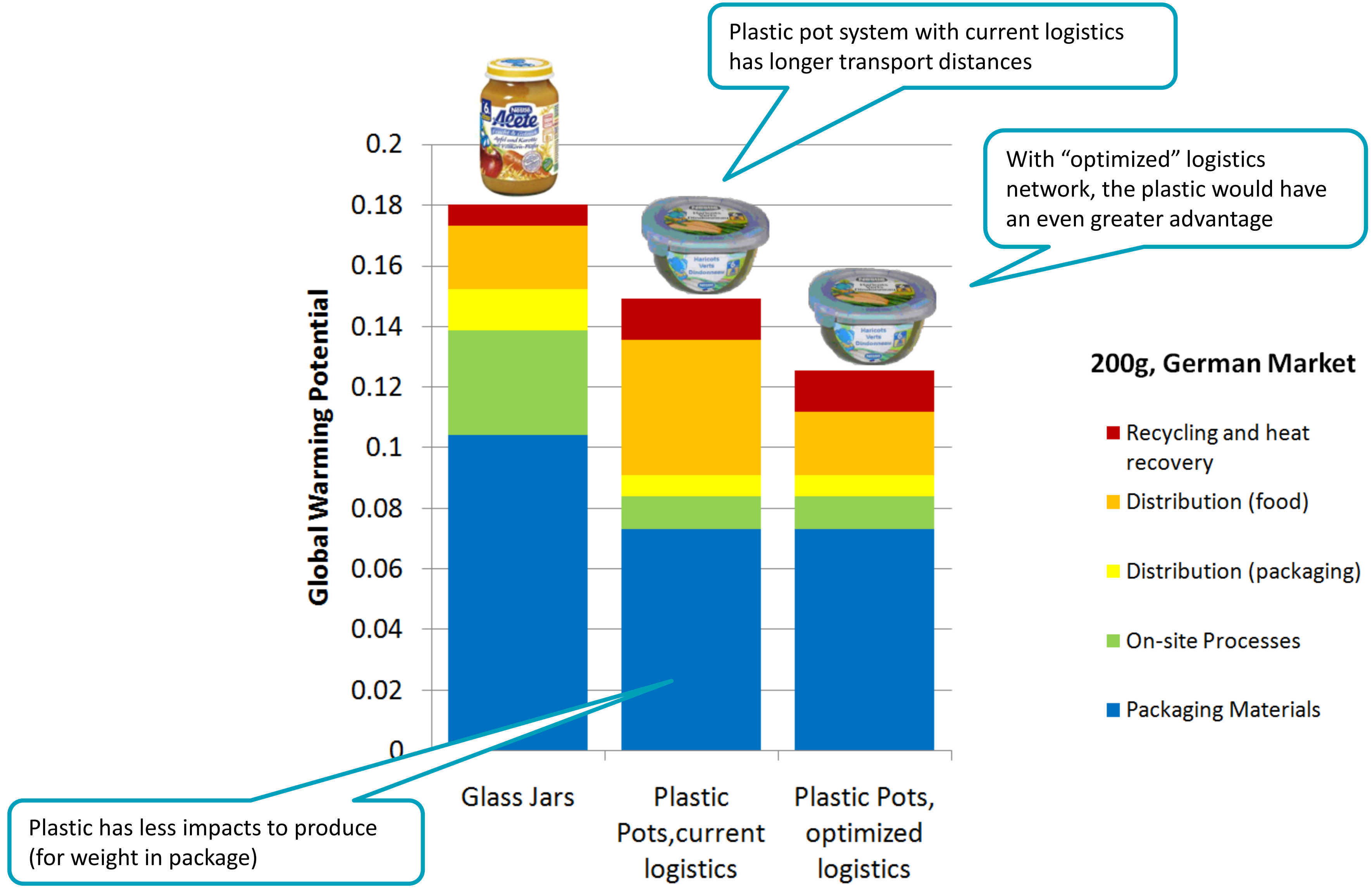
Plastic pot system with current logistics has longer transport distances
With “optimized” logistics network, the plastic would have an even greater advantage
Plastic has less impacts to produce (for weight in package)
Global Warming Potential
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Glass Jars
Plastic Pots,current logistics
Plastic Pots, optimized logistics
200g, German Market
Recycling and heat recovery
Distribution (food)
Distribution (packaging)
On-site Processes
Packaging Materials

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Life Cycle Assessment

LCA is regulated by ISO norms 14040 and 14044

Impact assessment based on best available science

Widely used as a decision making tool in R&D, companies, government, etc.

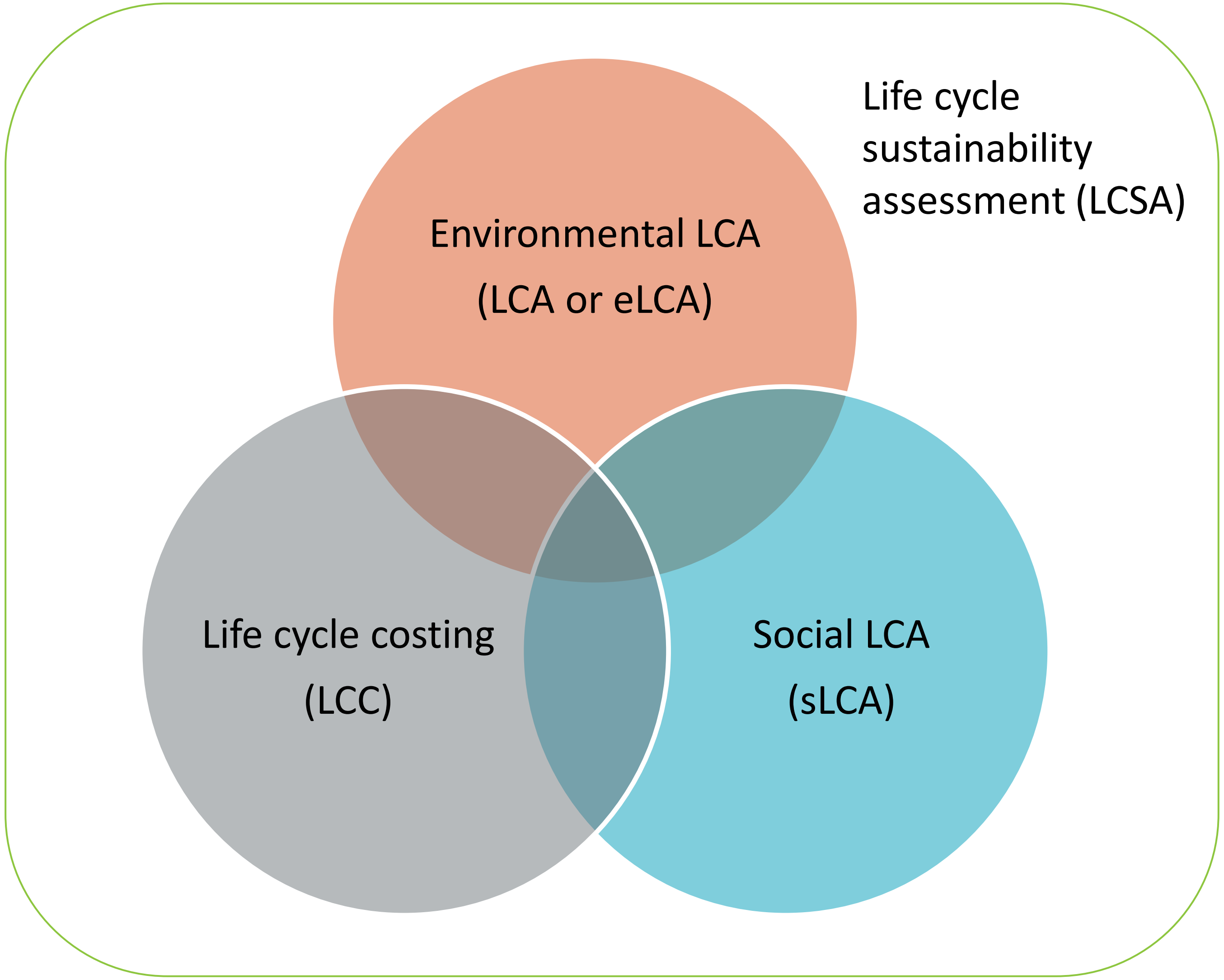
Yes, LCA has limits

- **It's a model of reality**
- **It assesses potential impacts, not real impacts**

BUT still useful because there is no other way to assess the impacts for all life cycle stages and for all impacts

→ *LCA provides valuable insights*

Different Life Cycle approaches toward sustainability



https://www.lifecycleinitiative.org/starting-life-cycle-thinking/life-cycle-approaches/life-cycle-sustainability-assessment/

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On the agenda today

- Presentation of teachers and students
- Presentation of the syllabus
- Introduction to the LCA project
- Why LCA
- High level introduction, familiarisation with the concept of life cycle
- Concluding remarks

Technosphere and Ecosphere

Technosphere

All human activities (production, consumption, processing, etc.)

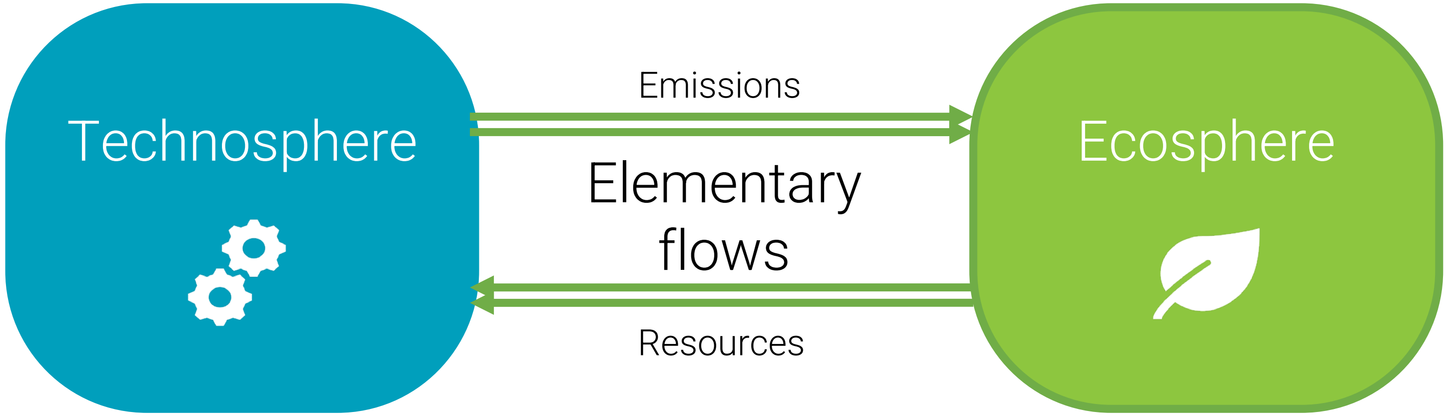
Ecosphere

The natural environment, including living organisms (biosphere), air, water, soil, and their natural resources (renewables or not)

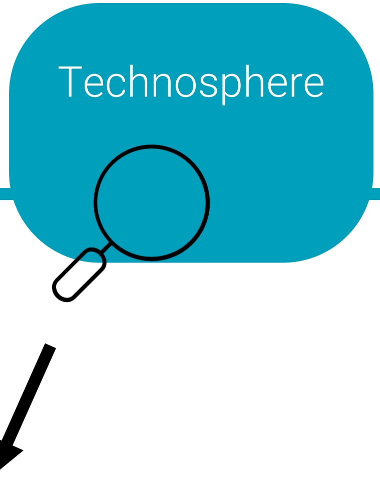
Elementary flows

- The ecosphere is the source of all raw materials used in the Technosphere
- The ecosphere is the sink for all the emissions from the Technosphere

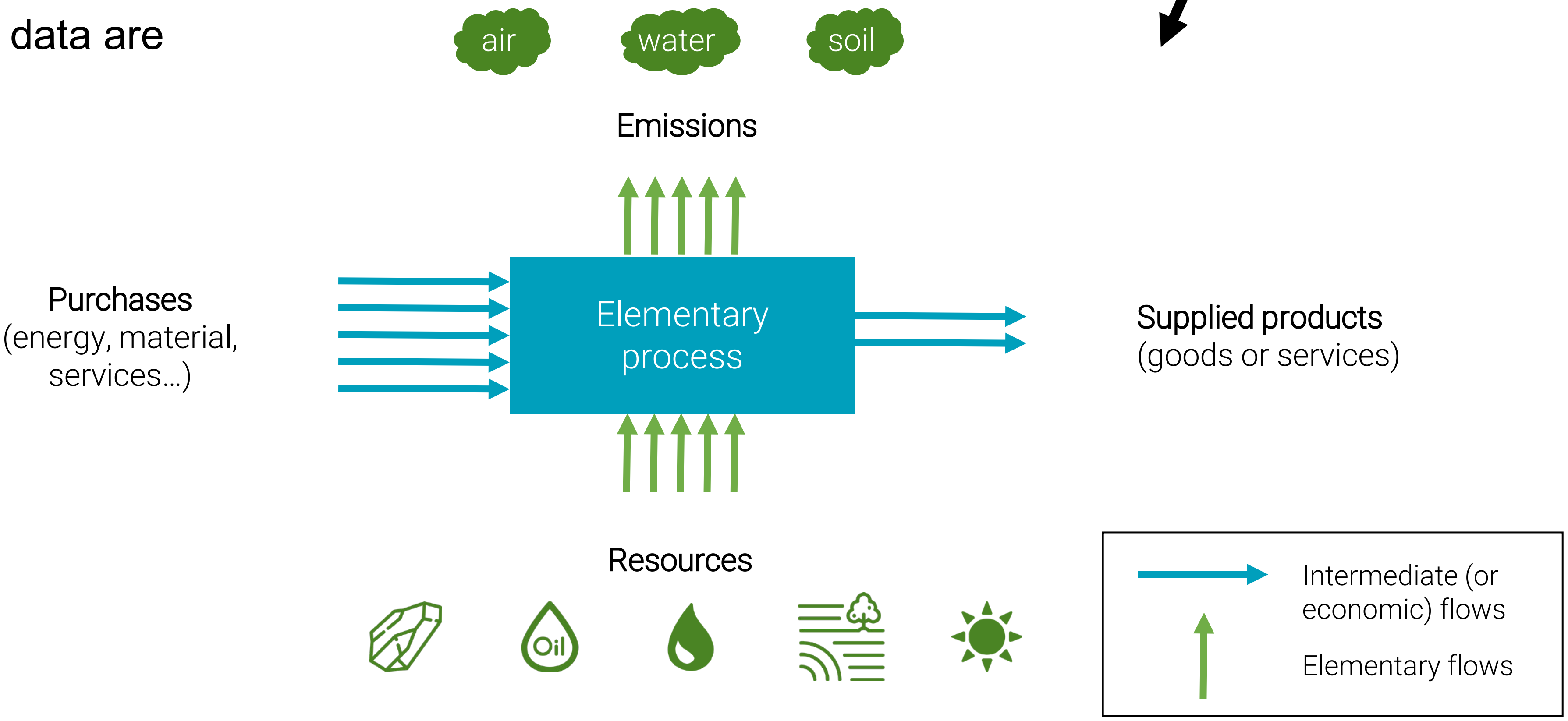
… these links or exchanges between the two spheres are called **Elementary flows** (or environmental interventions)



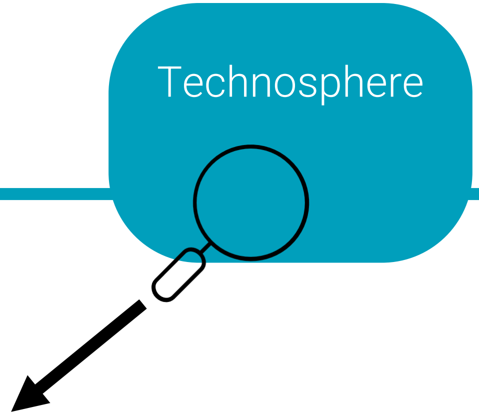
Elementary processes



smallest element considered in the life cycle inventory analysis for which input and output data are quantified

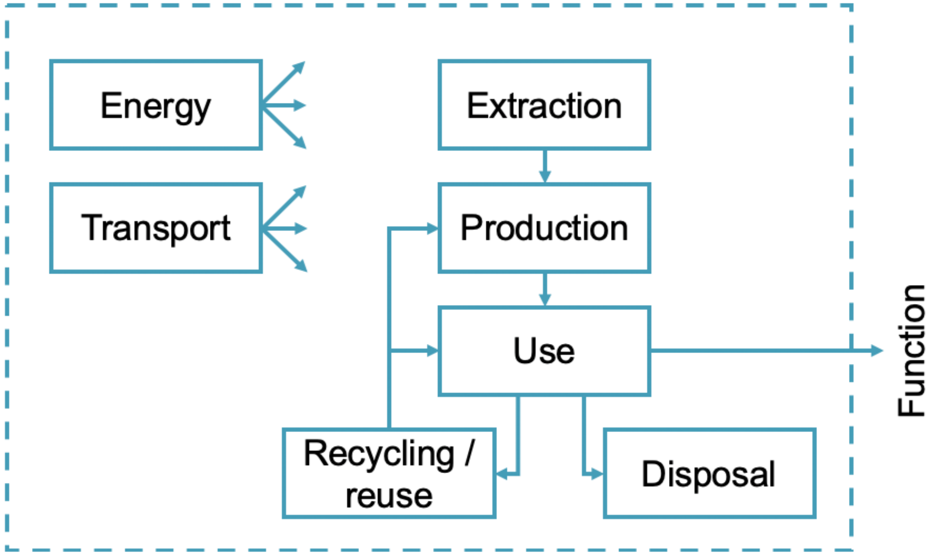


Product system– Simplified representation



Definition (ISO 14040)

« Set of elementary processes comprising product flows […], fulfilling one or more defined functions, which serve as a model for the life cycle of the product»



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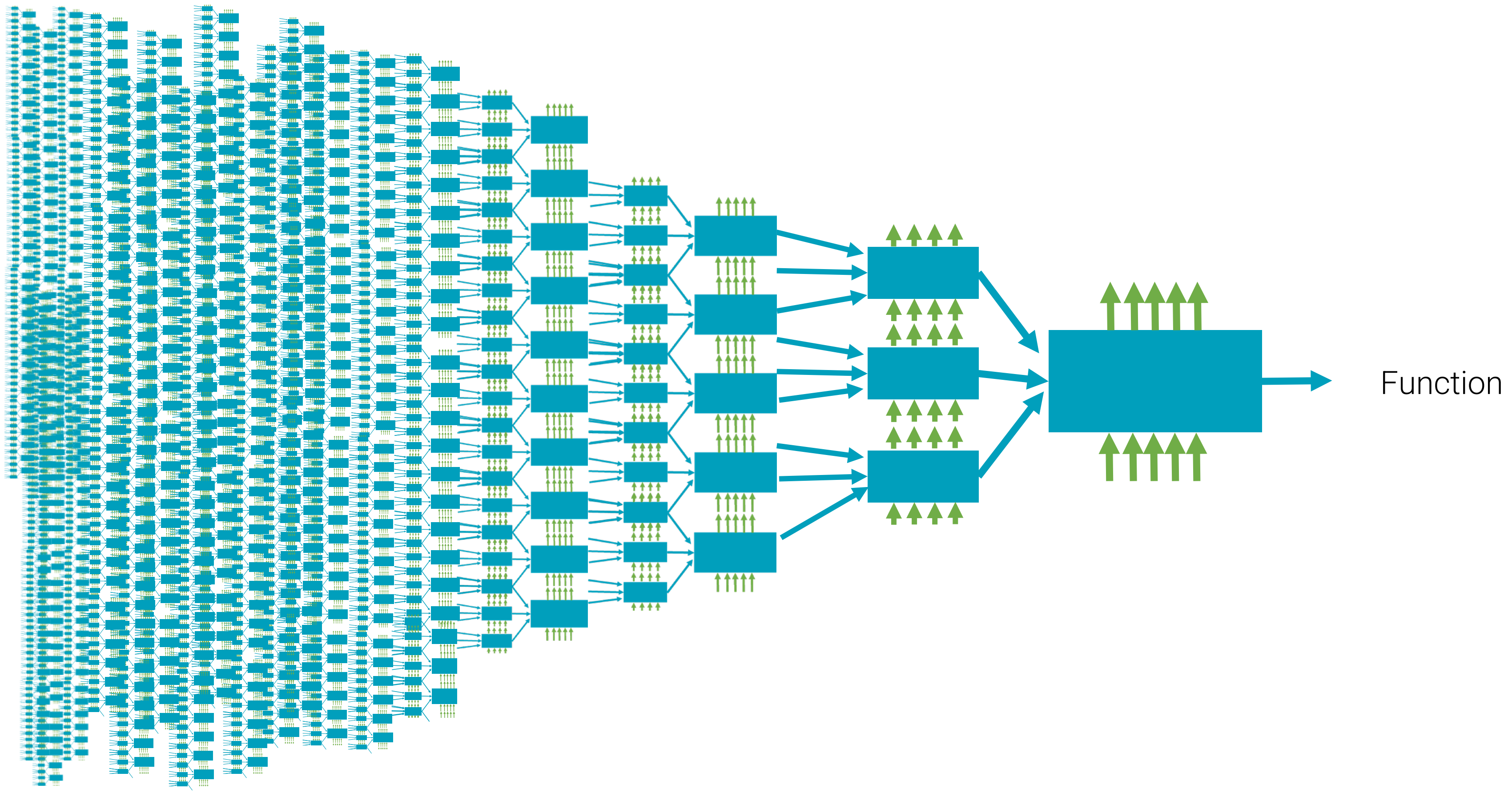
Product system– Realistic representation



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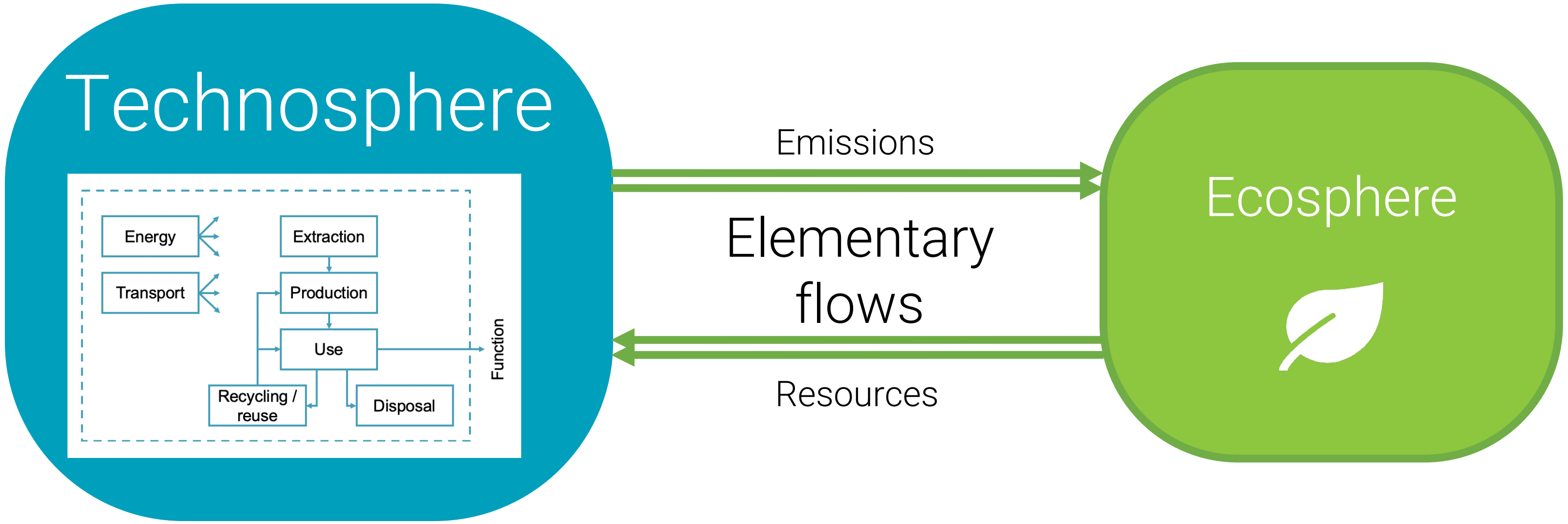
Product system

The product system is an integral part of the Technosphere

- It mobilizes part of the activities of the Technosphere
- It exchanges elementary flows with the ecosphere



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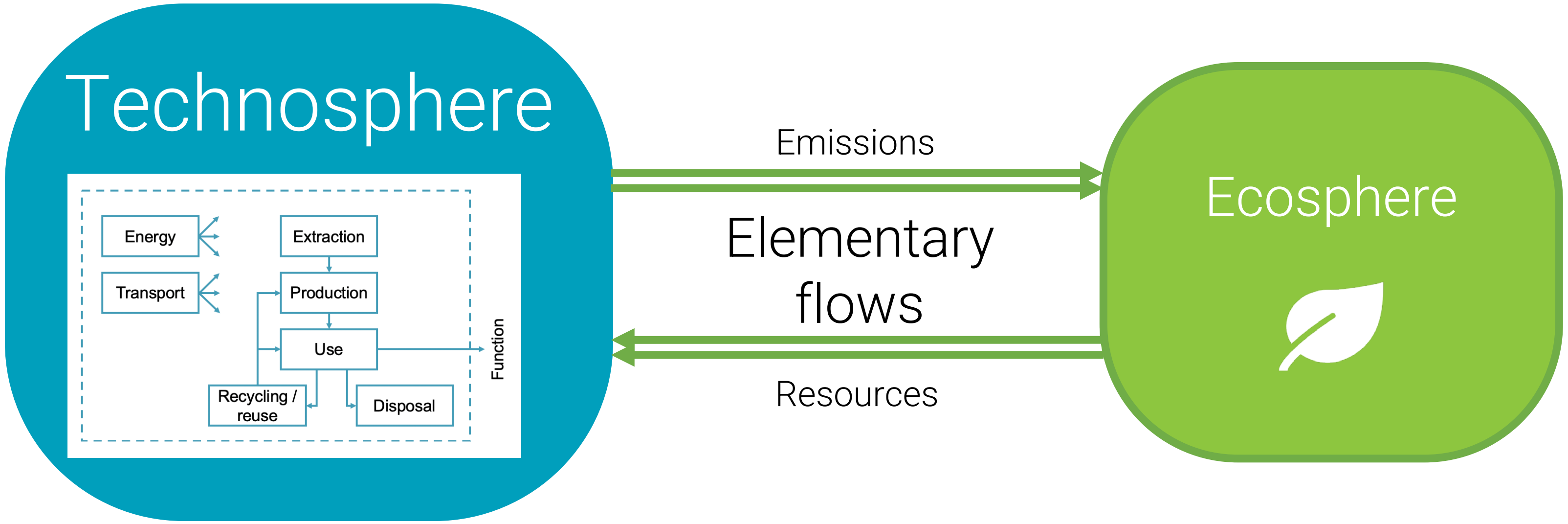
Conceptual model - summary

In summary, an LCA consists of:

1. Defining the product system (activities linked to a product / service)
2. Calculating all the exchanges between the product system and the environment (elementary flows)
3. Calculating the potential environmental impacts associated with these elementary flows



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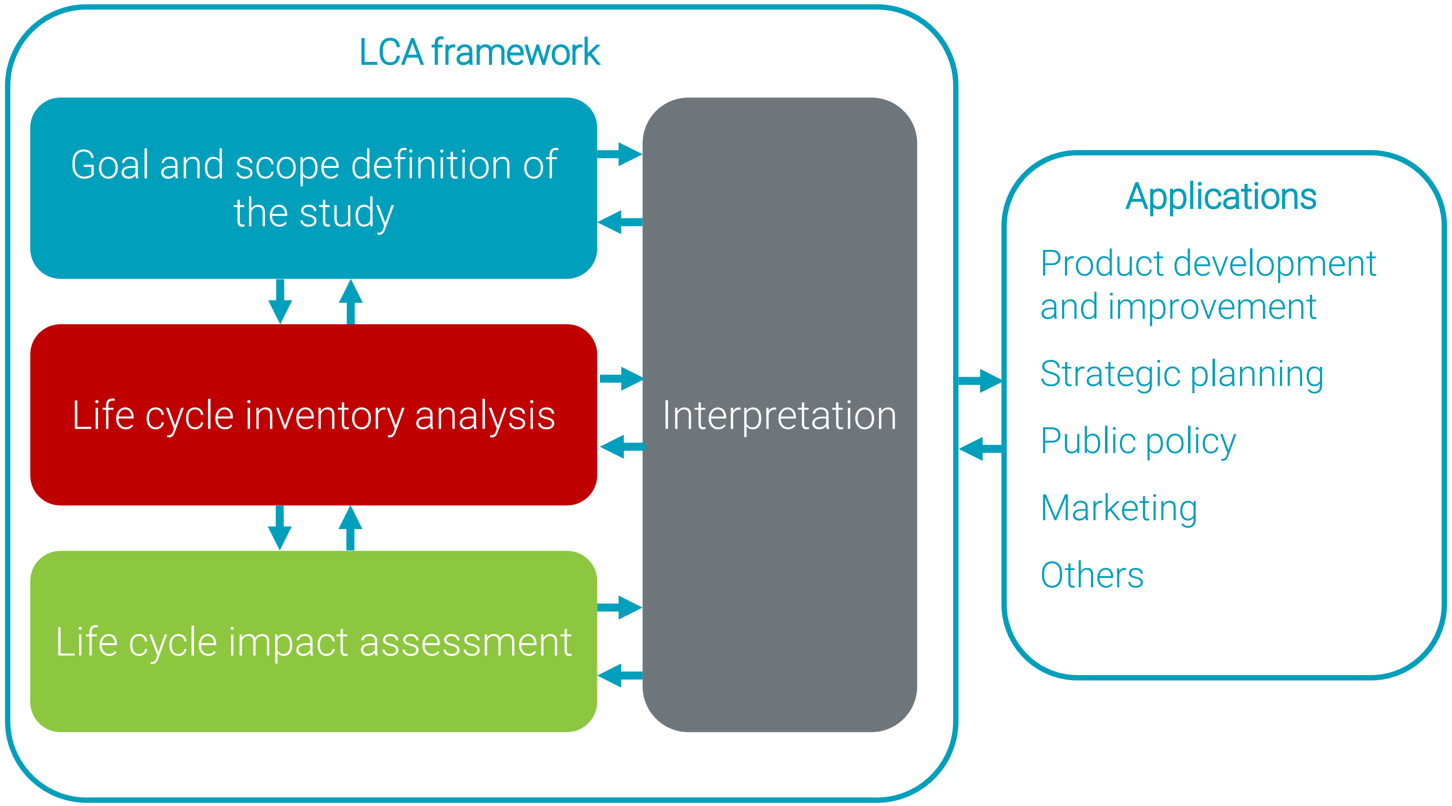
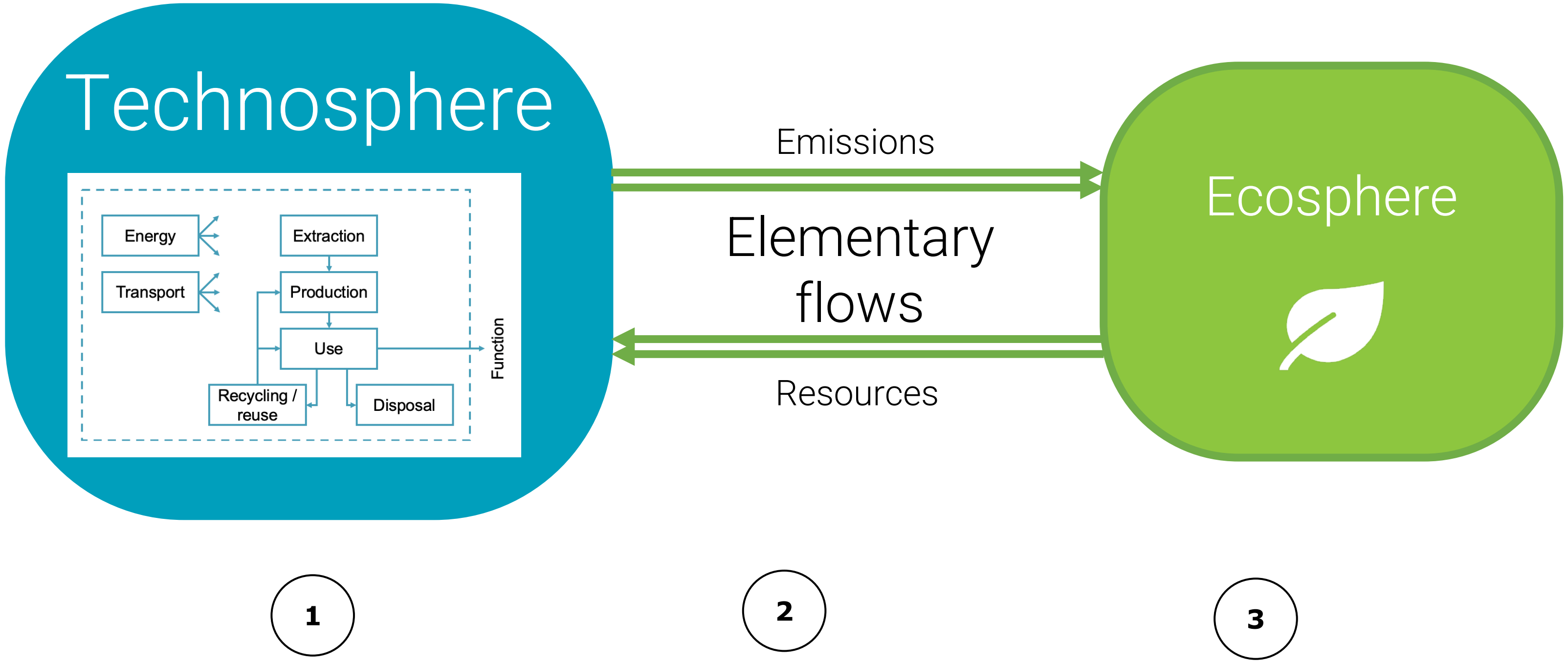
International standard ISO14040



Reminder: Conceptual model

The world is divided into two sphere which interact through elementary flows



LCA deals with these elements in three distinct phases

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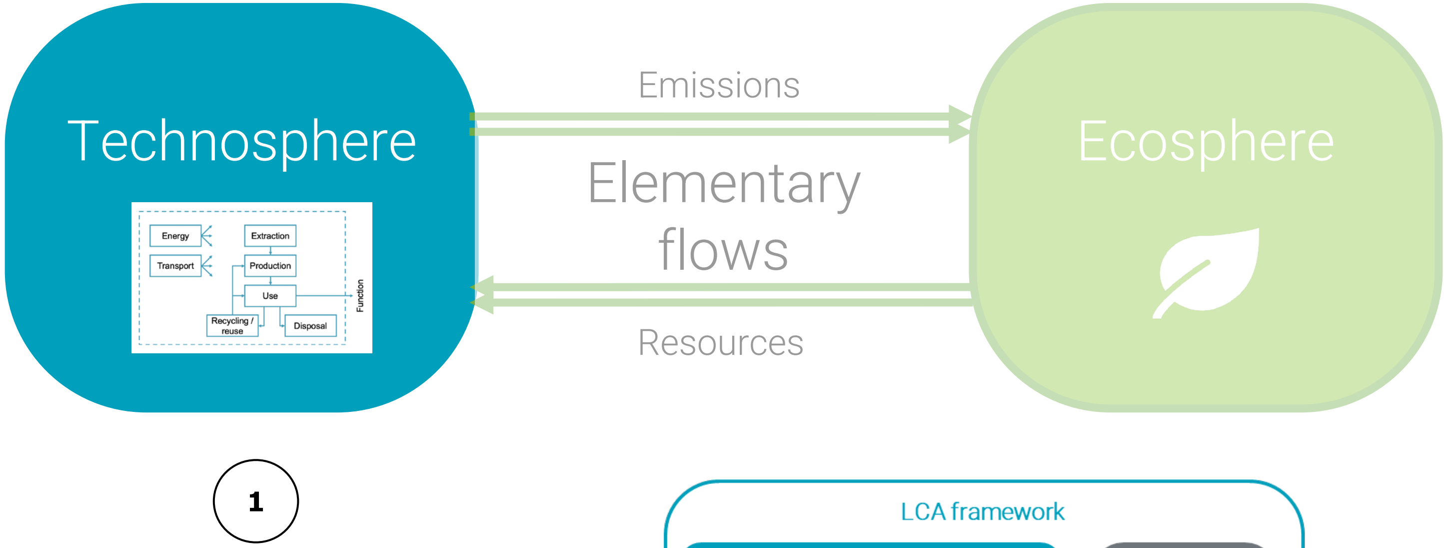
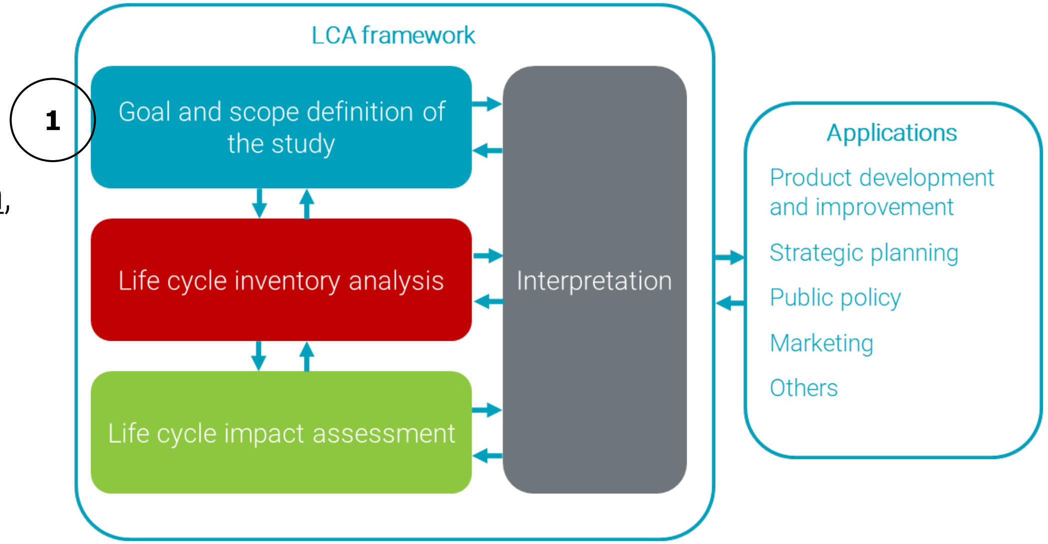
1. Goal and Scope definition of the study



Within the Technosphere, LCA is interested in a particular <u>product system</u>, which will be defined during the first phase of LCA



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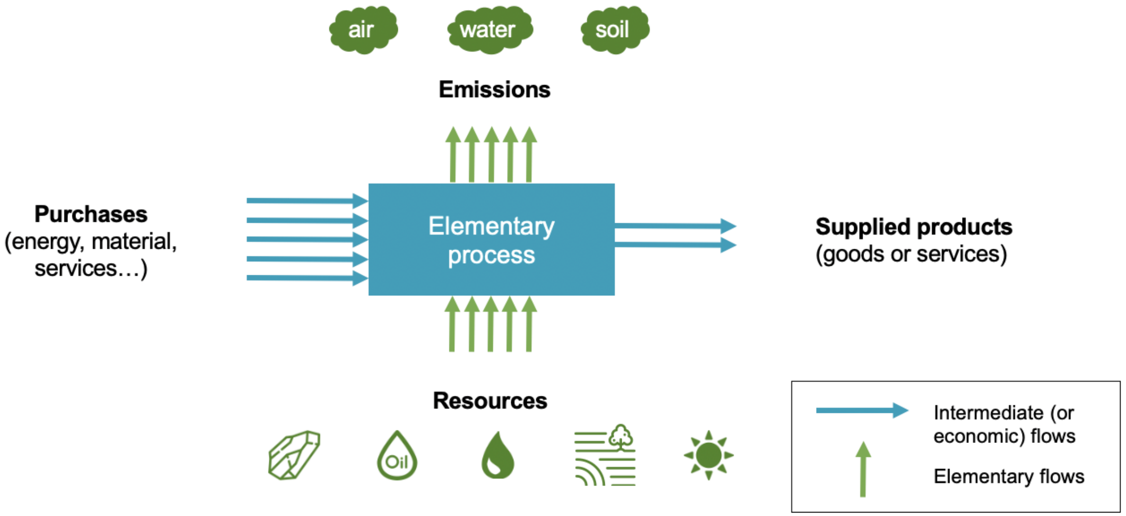
1. Goal and Scope definition of the study

A product system is made up of a series of « **elementary processes**»

- Basic elements of a product system

- Elementary flows: emissions/resources exchanged <u>directly</u> with the environment
- Intermediate flows: products or services exchanged with other elementary processes OR representing function under study



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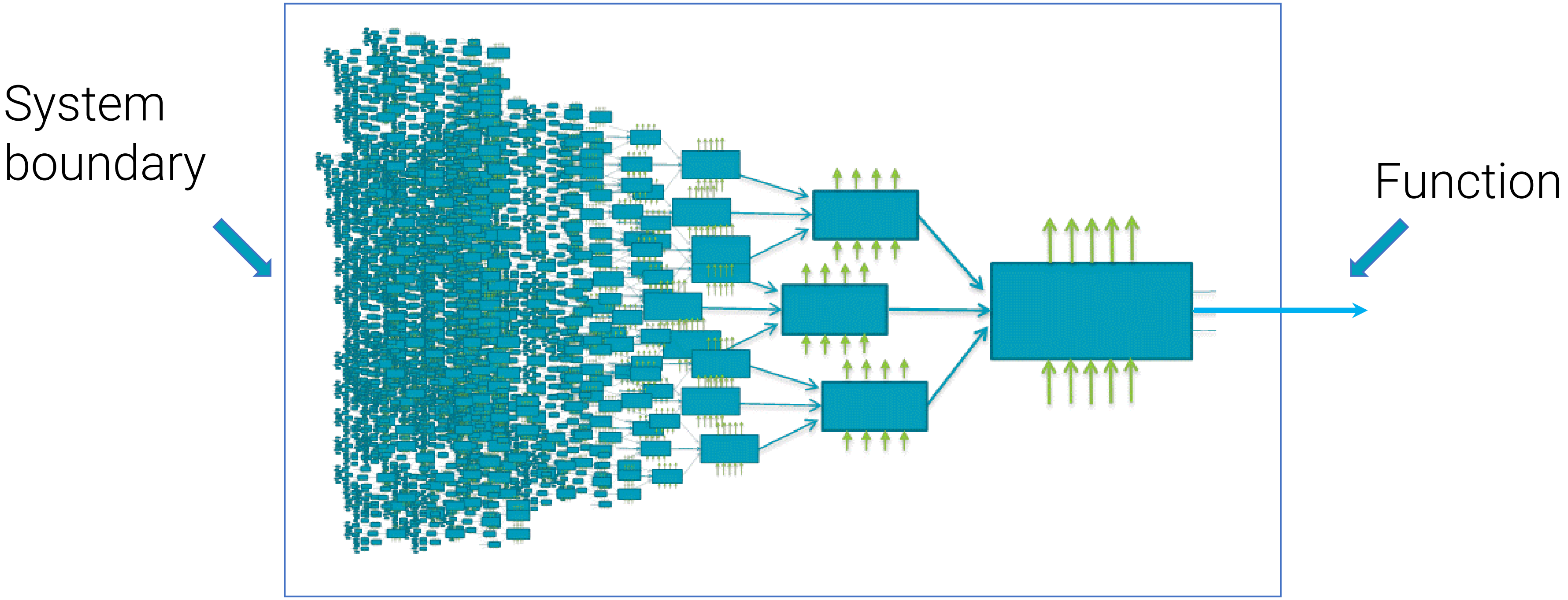
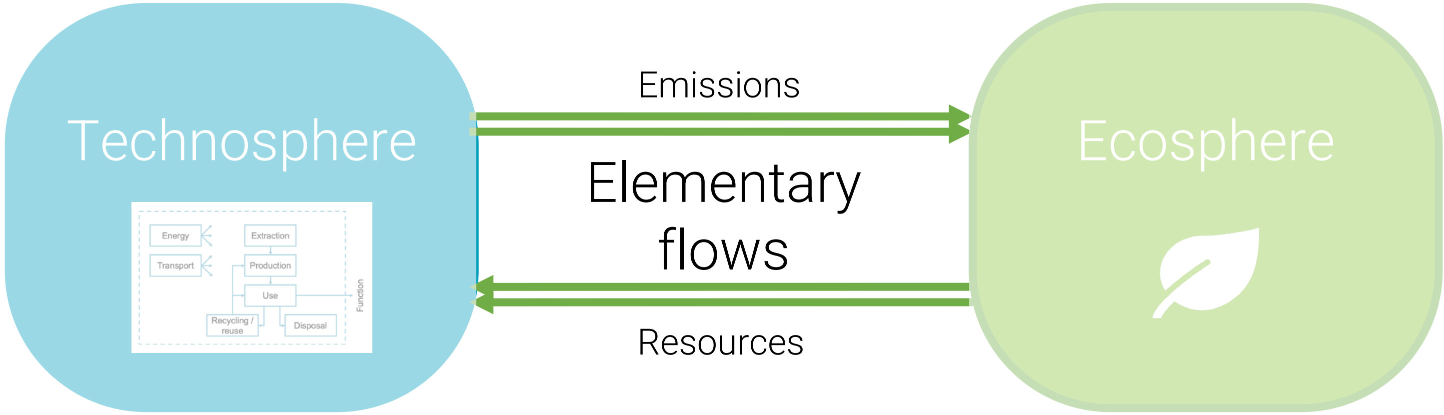
1. Goal and Scope definition of the study

Each elementary process requires the product of other elementary processes within the product system

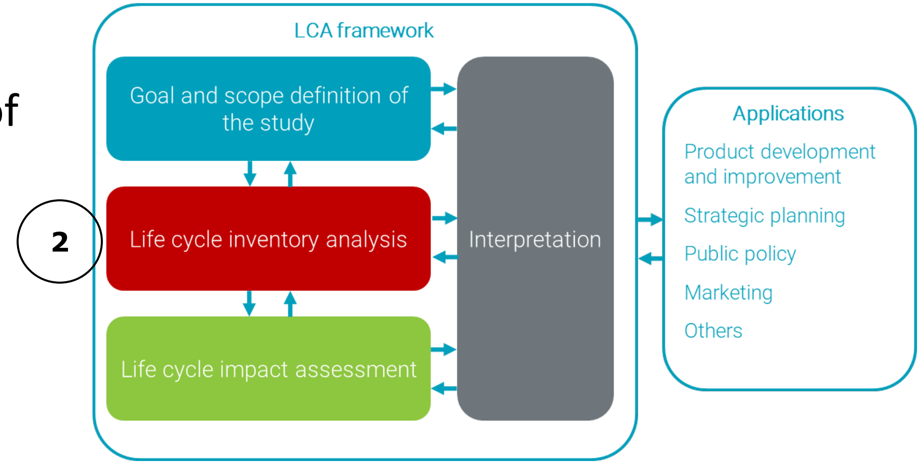


2. Life Cycle Inventory (LCI)



2

The life cycle inventory records the elementary input and output flows of the product system



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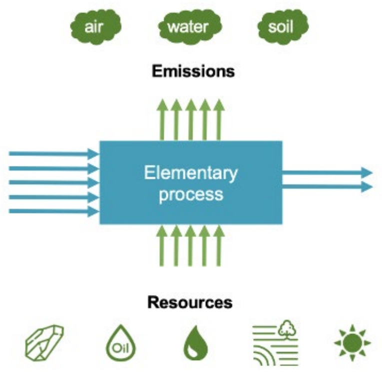
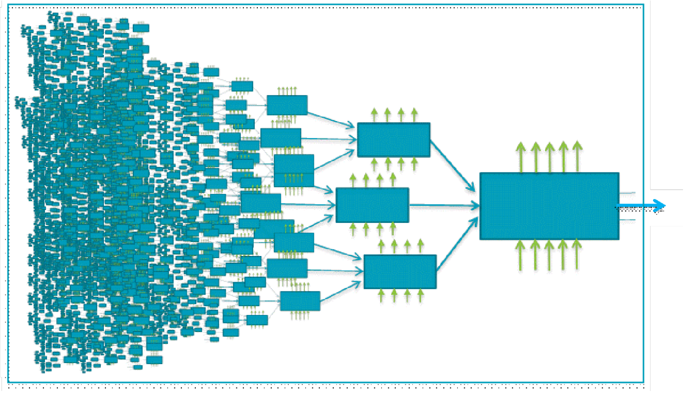
2. Life Cycle Inventory (LCI)

« Life cycle inventory phase involves the compilation and quantifications of inputs and outputs , for a given product system during its life cycle» (ISO 14044)



Elementary flows for an elementary process



Elementary flows for each elementary process

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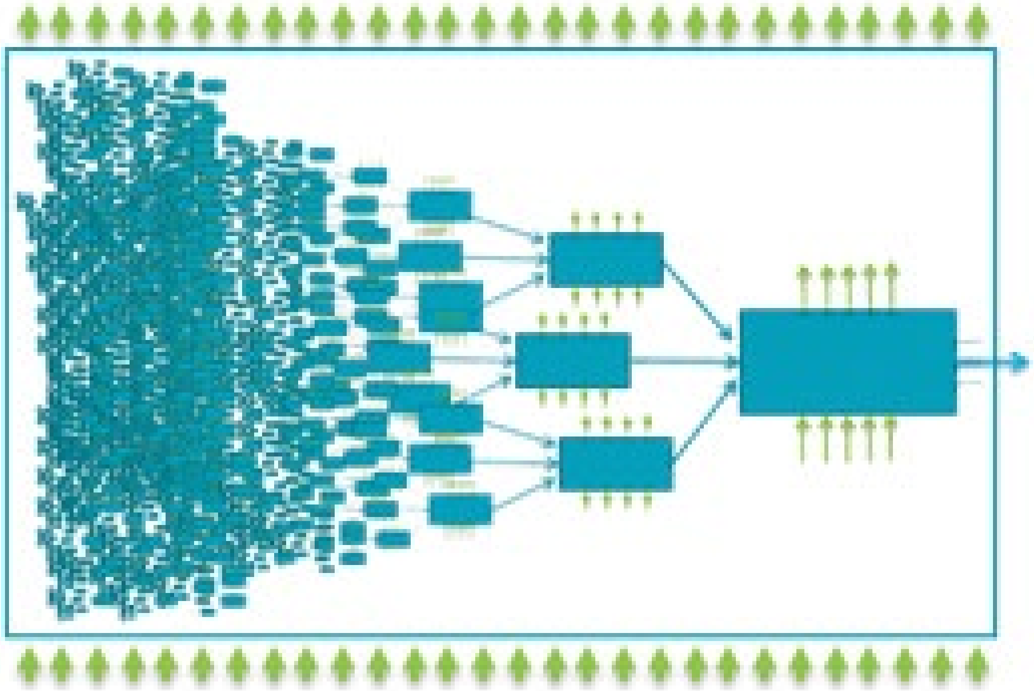
2. Life Cycle Inventory (LCI)

LCI = sum of elementary flows of each process (scaled to the functional flow)



Functional flow

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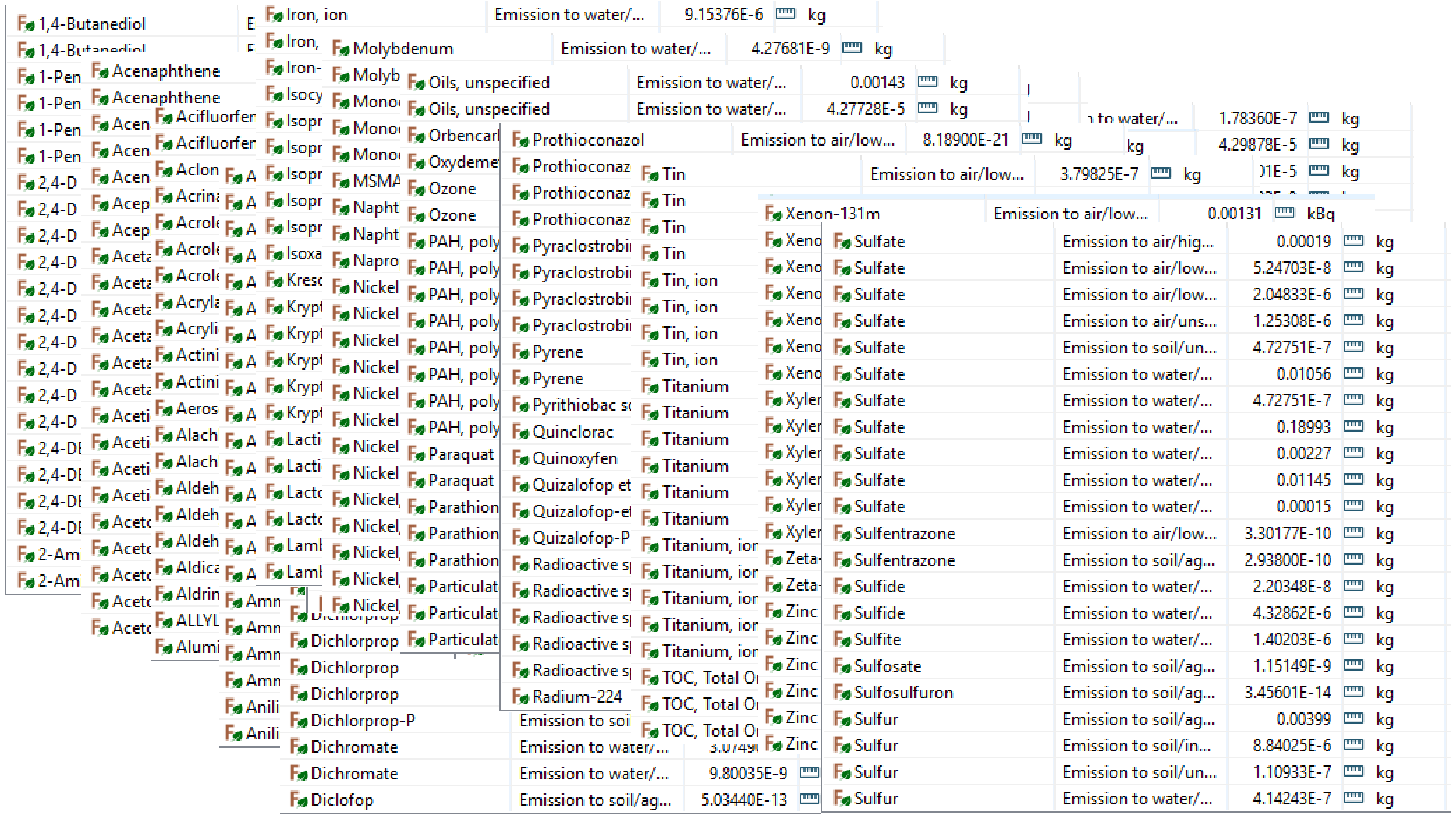
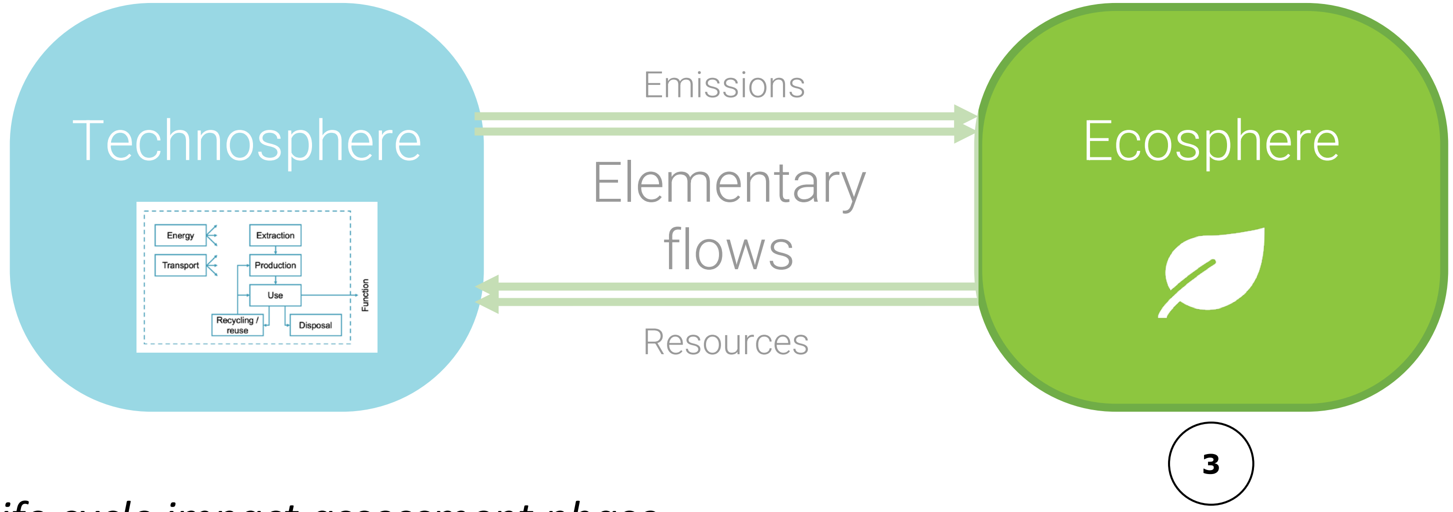
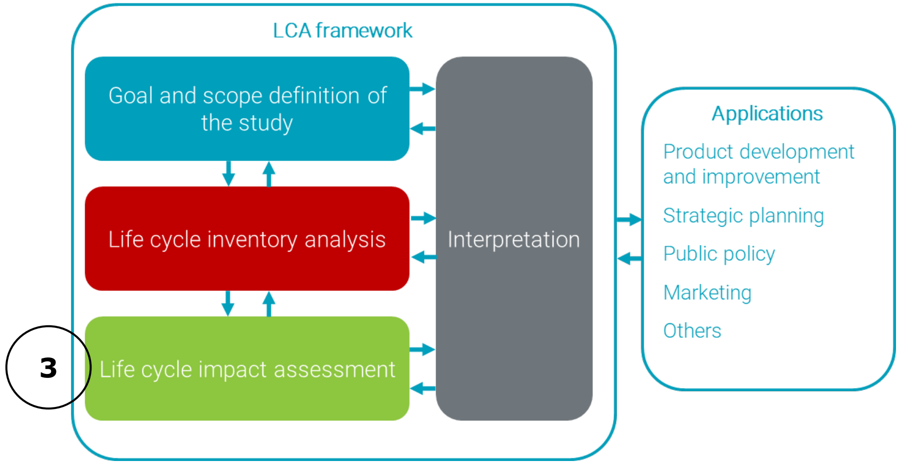
2. Life cycle inventory (LCI)– concrete example



3. Life Cycle Impact Assessment (LCIA)



« Life cycle impact assessment phase intends to understand and assess the magnitude and significance of the potential impacts of a product system on the environment during its life cycle» (ISO 14044)



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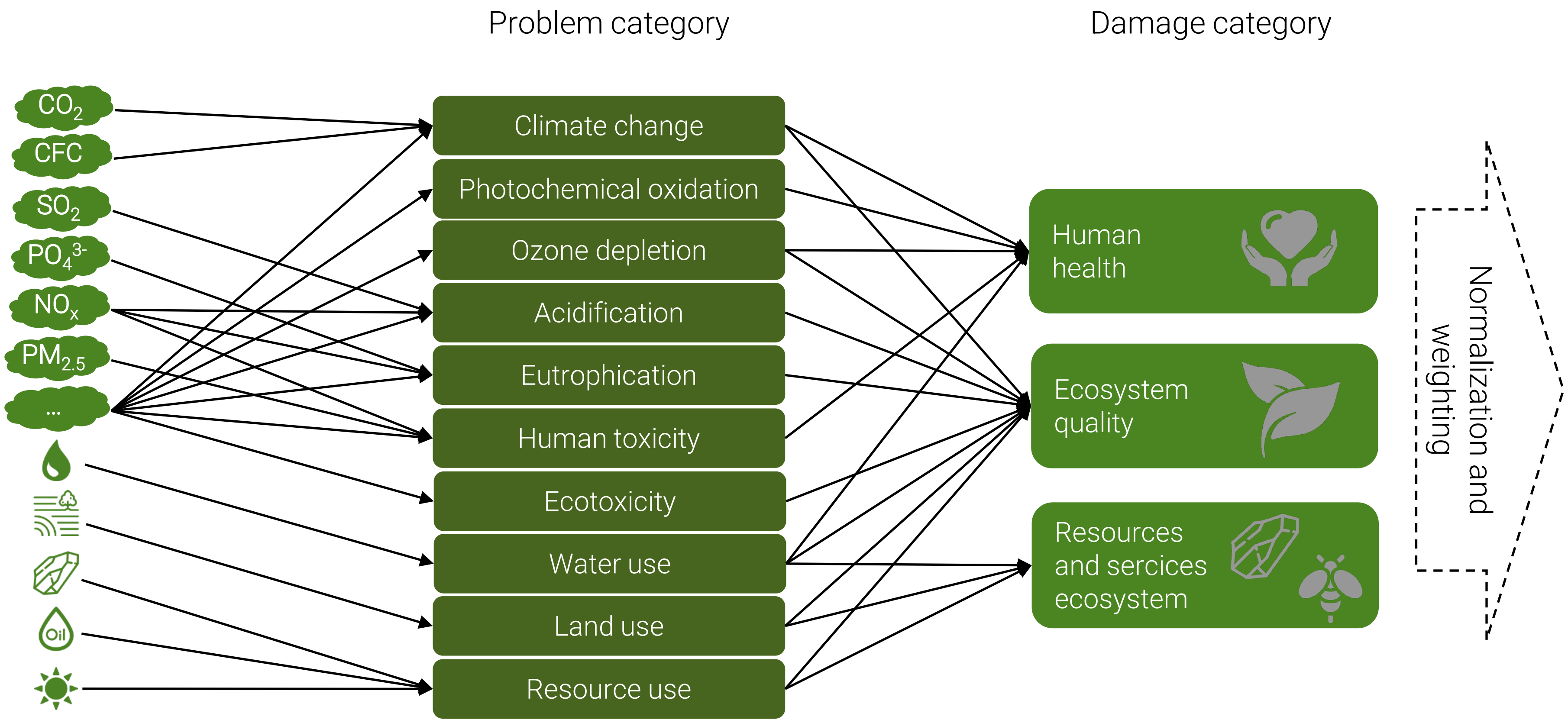
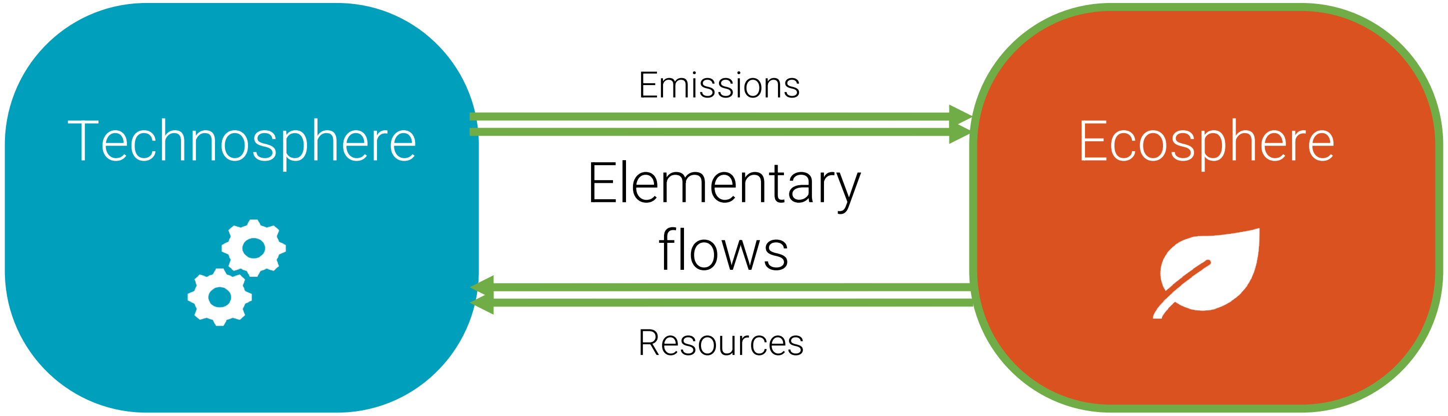
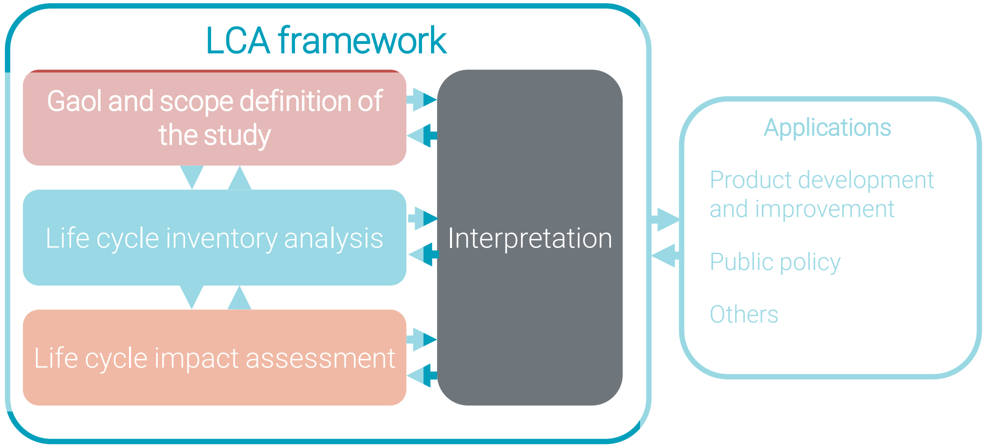
3. Life Cycle Impact Assessment (LCIA)



4. Interpretation of results



« The results of an LCI or an LCIA are summarized and discussed to draw conclusions, recommendations, and lead to a decision-making in accordance with the goal and scope definition of the study» (ISO 14044)



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4. Interpretation of results

- To get impact scores, we make tens of hypotheses, and lots of calculations
- We need to put things in perspective, understand what the quantitative results really mean in the context of decision making and in relationship to the question asked by the commissioner (goal of the study).

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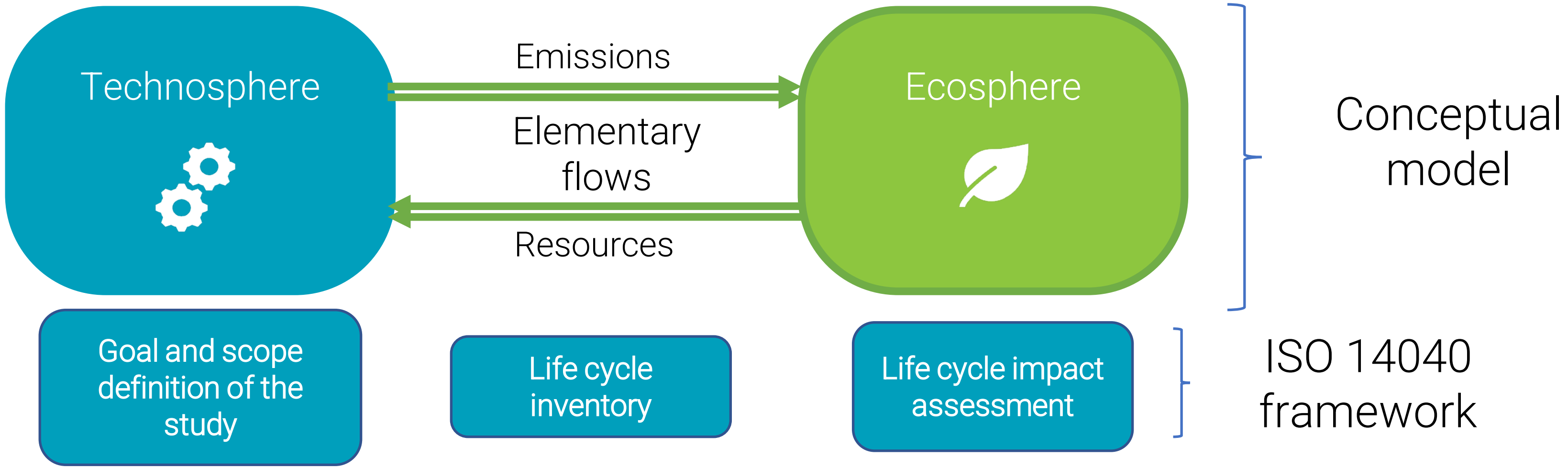
Conceptual model and ISO 14040 analysis framework

In summary, an LCA consists of:

1. Defining the product system (activities linked to a product / service)
2. Calculating all the exchanges between the product system and the environment (elementary flows)
3. Calculating the potential environmental impacts associated with these elementary flows
4. … without forgetting to interpret the results according to the goal of the study (ISO 14040)



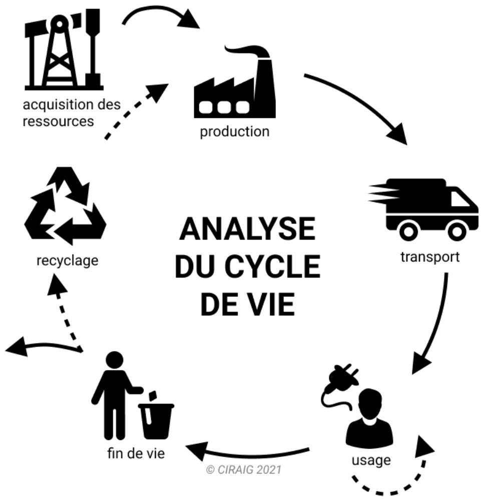
On the agenda today

- Presentation of teachers and students
- Presentation of the syllabus
- Introduction to the LCA project
- Why LCA
- High level introduction, familiarisation with the concept of life cycle
- Concluding remarks

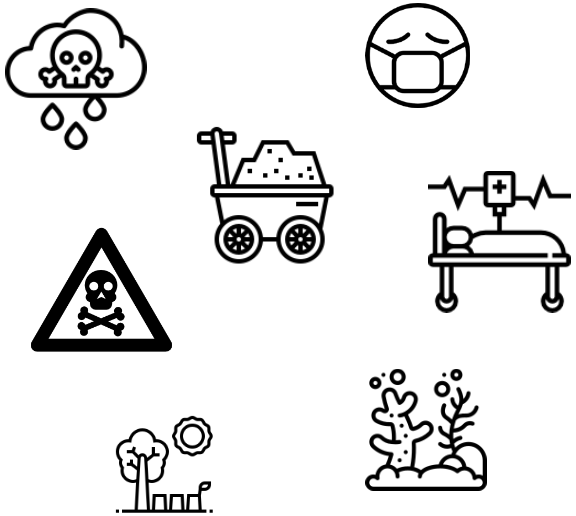
Biggest strength of LCA: holistic dimension

- **Takes into account « all » economic activities associated to a product or to a decision.**
- **Takes into account a comprehensive set of environmental impacts**
- **This allows to avoid *burden shifting***

Value chain



Multi indicators



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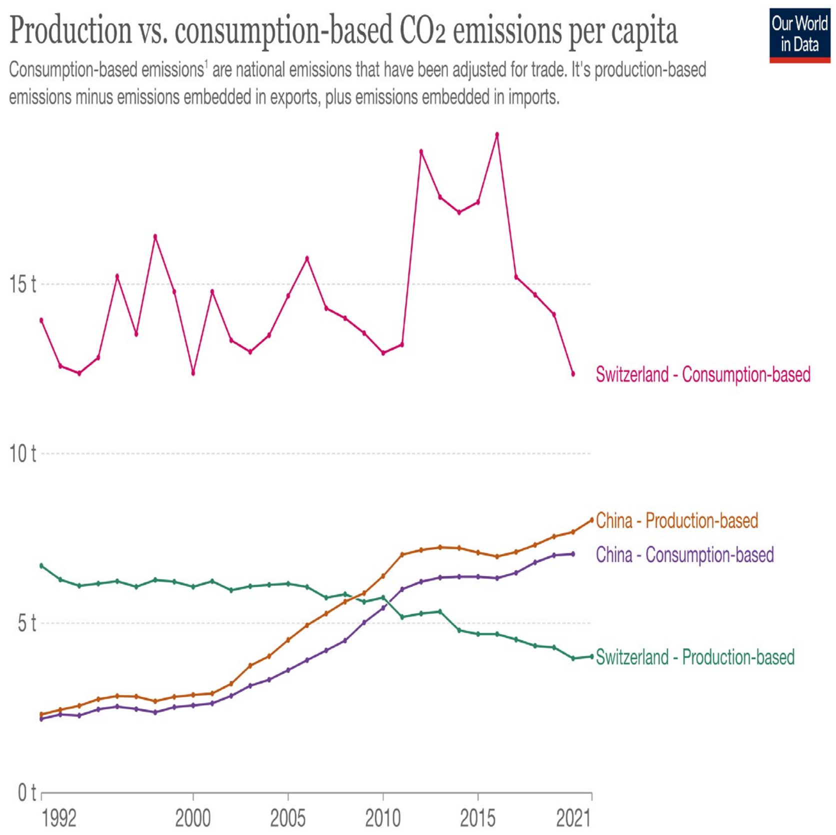
Life cycle thinking - Ethical question

- Who is responsible for the pollution?
- Why?
- What does it mean to be « responsible »?

Life cycle thinking - Ethical

« We produce products and these products are consumed by other countries, especially the developed countries. This share of emissions should be taken by the consumers but not the producers »

Li Gao, Chinas's chief climate negotiator, 2009



Conclusions

- Environmental issues usually lead to
  - **Emotional reactions**
  - **Political speeches**

  A playing field for the dissemination of ideas, prejudice, power dynamics, etc.
- LCA doesn't have the answer to these questions and though it is imperfect, it is:
  - **Science-based, data driven**
  - **Holistic**
  - **Nuanced, i.e. allows to identify trade-offs**
- LCA is a diagnostic tool which tries to see things as they are and to put them in perspective.

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Conclusion

- LCA is a tool to **<u>help</u> decision-making**
  - **LCA does not make a decision**
  - **It gives a vision of reality to <u>inform</u> decision-makers on the environmental dimension**
  - **But decisions are based on:**
    - values;
    - Ethical considerations, morals, beliefs (religious or other);
    - Political ideology;
    - Economics;
    - Practical considerations

LCA does not have all the answers:
decision-makers shall assume their responsibility

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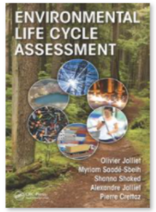
Conclusion

Reading suggested:

https://doi.org/10.1201/b19138

- Chapter 1
- Chapter 2



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Book

Environmental Life Cycle Assessment

By Olivier Jolliet, Myriam Saade-Sbeih, Shanna Shaked, Alexandre Jolliet, Pierre Crettaz

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Subjects	Environment & Agriculture, Environment and Sustainability
OA Funder	Knowledge Unlatched GmbH

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- Life cycle assessment: past, present and future

Environ. Sci. Technol. 2011, 45, 90–96

Life Cycle Assessment: Past, Present, and Future†

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Received April 23, 2010. Revised manuscript received August 10, 2010. Accepted August 17, 2010.

examples are baby diapers (pap
packaging (glass versus plastic v
It has been recognized that, f
a large share of the environment
of the product but in its prod
disposal. Gradually, the import
cycle of a product, or of several al
an issue in the 1980s and 1990s. (
of life cycle assessment (LCA), th
ation of the inputs and outputs
mental impacts of a product syste
(2, 3). In Figure 1, the emergence
by a literature count of LCA art
Governments all over the worl
Increasingly, LCA has become a
mental policy or in voluntary acti
the USA, Japan, Korea, Canada,
booming economies as India ar
Along with the popularity o
creative use. We now see LCA stu
building materials, military syste
while the earlier studies were

Group exploration of LCA concepts

Question 1: Environmental impacts of a product

- **Choose a random product**
- **What should we consider in the evaluation of the environmental impacts of that product?**

Question 2: Environmental comparison of the products

- **What product could we compare the first one to?**
- **Repeat exercise 1 for the alternative product.**
- **How could we be sure that the comparison is a valid one?**