The Limits to Growth: Sustainability and the Circular Economy

Lecture 5: Lifecycle Assessment (LCA)

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License

EXERCISE E03 – FAVORITE FRUIT/VEGETABLE

INTRODUCTION

LCA – Motivation

LCA – Motivation

Battery Electric Vehicles (EV)

Or

Internal Combustion Engine Vehicles

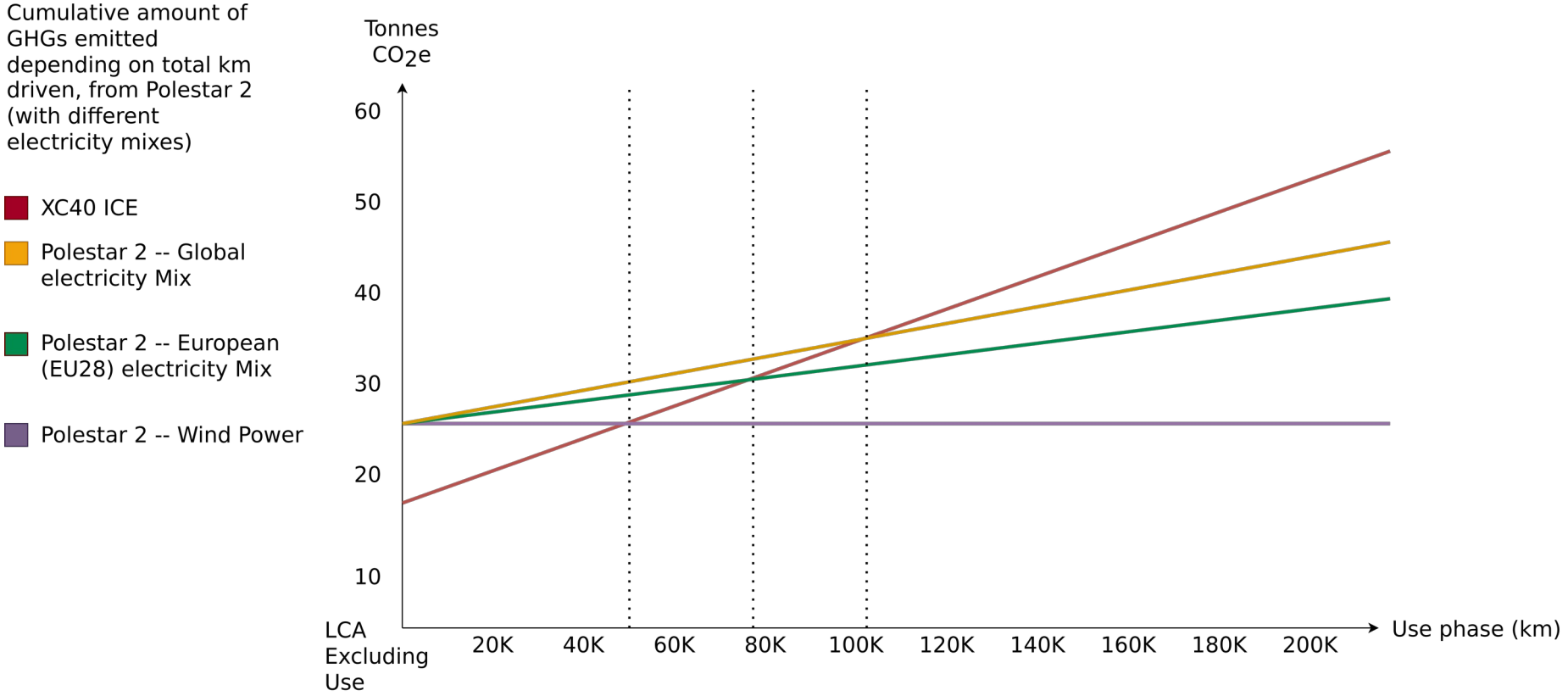
EV Break-Even Point?

What is the **break-even** point (in km) after which an EV would have caused fewer emissions than an Internal Combustion Engine (ICE?)

a. 0 – 50.000km
b. 50.000 – 100.000km
c. 100.000 – 150.000km
d. 150.000 – 200.000km
e. After 200.000km

Life Cycle Assessment – Polestar 2

Cumulative amount of GHGs emitted depending on total km driven, from Polestar 2 (with different electricity mixes)



Number of kilometers driven at break-even between Polestar 2 with different electricity mixes in the use phase of XC40 ICE (petrol)

Electric mix	Break-even (km)
Polestar 2 -- Global electricity Mix	112,000
Polestar 2 -- European (EU28) electricity Mix	78,000
Polestar 2 -- Wind Power	50,000

Polestar (2020) – Life Cycle Assessment – Carbon Footprint of Polestar 2.

LIFECYCLE ASSESSMENT (LCA)

Lifecycle Assessment (LCA)

Definition

“LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product’s lifecycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e., cradle-to-grave).” -- ISO 14040

ISO 14040 Environmental management — Life cycle assessment — Principles and framework, International standards organisation (https://www.iso.org/standard/37456.html)

Lifecycle Assessment (LCA)
ISO 14040 & ISO 14044

- The ISO 14040/14044 (ISO14040, 2006) (ISO14044, 2006) together provide a *loose* methodology for conducting LCA studies.
- ISO 14040 defines the *principles and framework* of the standard
- ISO 14044 provides *requirements and guidelines* for LCA practitioners.

- Their scope is very broad, hence requiring LCA practitioners to further refine the methodology for their specific needs.

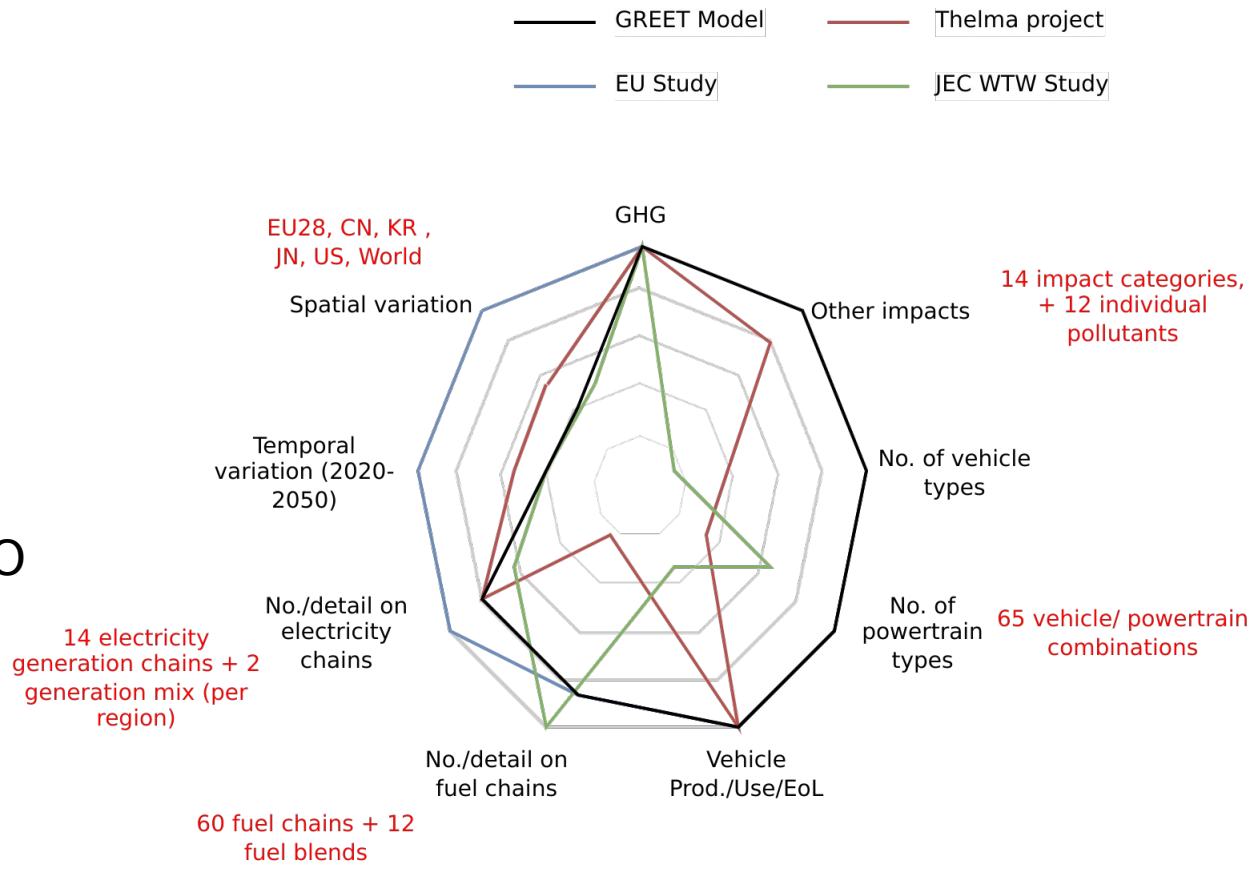
ISO 14040 Environmental management — Life cycle assessment — Principles and framework, International standards organisation (https://www.iso.org/standard/37456.html)

ISO 14044 Environmental management — Life cycle assessment — Requirements and guidelines, International standards organisation (https://www.iso.org/standard/38498.html)

Running Case Study

2020 EU Commission Report

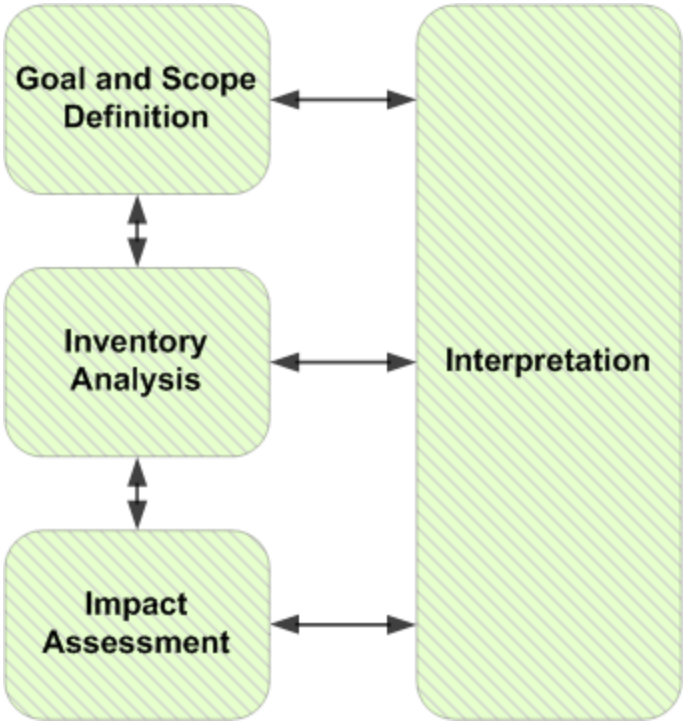
- *"Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA"*
  - Prepared by *Ricardo Energy and Environment*
  - Generally follows the ISO 14040 and ISO 14044 standards.



Overview of the LCA Application framework and key data flows, in comparison with other studies

Image adapted from Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA, Ricardo Energy and Environment (Link)

Four main phases of LCA



GOAL AND SCOPE DEFINITION

Goal and Scope Definition

Goal of an LCA study

- **ISO 14040 definition**
- The goal of an LCA states:
  - The intended application
  - The reasons for carrying out the study
  - The intended audience
  - Whether the results are intended to be used in comparitive assertions released publicly

- **2020 EU Study**
  - Explores the environmental impact of a representative selection of road vehicle configurations in a holistic manner.
  - Aims to enhance the Commission's understanding of environmental impacts and of suitable methodologies to assess them in the mid- to long-term time frame (until 2050).
  - Targets an audience comprising primarily the European Commission and secondarily decision-makers in general.

ISO 14040 Environmental management — Life cycle assessment — Principles and framework, International standards organisation (https://www.iso.org/standard/37456.html)

Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA, Ricardo Energy and Environment (Link)

Goal and Scope Definition

Scope of an LCA study

- **ISO 14040 standard**
- The scope of an LCA should describe:
  - **The functional units of the system(s)**
  - **Reference flows**
  - The system boundary
  - LCIA methodology and types of impacts analysed
  - *Limitations*
  - *Data quality requirements*
  - …

quantified performance of a product system for use as a reference unit

measure of the outputs from processes in a given product system required to fulfill the function expressed by the functional unit

ISO 14040 Environmental management — Life cycle assessment — Principles and framework, International standards organisation (https://www.iso.org/standard/37456.html)

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  - …

- **2020 EU Study**
- Functional Units
  - Based on vehicle size and utility

Body Type	Passenger Car	Van	Rigid Lorry	Artic Lorry	Urban bus	Coach
Default reference flow	Vehicle-km (vkm)	Vehicle-km (vkm)	Tonne-km (tkm)	Tonne-km (tkm)	Vehicle-km (vkm)	Vehicle-km (vkm)

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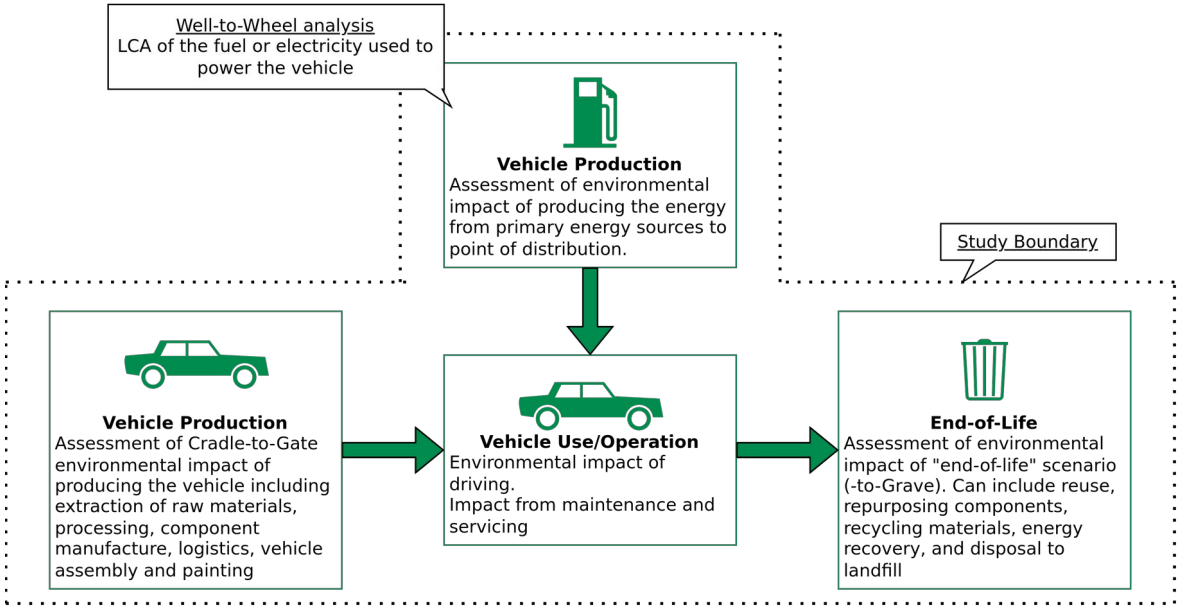
- **2020 EU Study system boundary**



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Goal and Scope Definition

Quantitative definition of system boundaries – the Cut-off criteria

- In general, all processes and flows that are attributable to the analysed system are to be included in the system boundaries.
- **However, not all of them are quantitatively “relevant”**.
- For less relevant ones, data of lower quality (estimates) can be used, limiting the effort for collecting high quality data.
- Irrelevant ones, can be entirely “Cut-off”

ILCD Handbook – General guide for Life Cycle Assessment – Detailed Guidance (Link)

Goal and Scope Definition

Quantitative definition of system boundaries – the Cut-off criteria

- “Cut-off” refers to the omission of not relevant life cycle stages, activity types (e.g. investment goods, storage, …), specific processes and products and *elementary flows* from the system model.
- Cut-offs are quantified in relation to the percentage of environmental impacts that is approximated to be excluded via the cut-off.
- e.g., "95 %" relates to cutting off about 5 % of the total environmental impact (or of a selected impact category)

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- Cut-offs are quantified in relation to the percentage of environmental impacts that is approximated to be excluded via the cut-off.
- e.g., "95 %" relates to cutting off about 5 % of the total environmental impact (or of a selected impact category)
- **BUT,** this would require an approximation of 100% of the impact, because if we already knew what 100% impact is, we wouldn’t be doing the study anyway.
- **IMPORTANT:** Cut-off should not be so big, or you can risk having incomplete data (meaning lower environmental impacts) and also overall uncertainity.

ILCD Handbook – General guide for Life Cycle Assessment – Detailed Guidance (Link)

Goal and Scope Definition

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  - …

- **2020 EU Study**

Impact Category	Indicator and unit
Climate change	Greenhouse gas emissions GWP100 in CO_2 eq (including carbon feedbacks)
Energy consumption	Cumulative energy demand in MJ: non-renewable (fossil and nuclear) and renewable
Acidification	Acidification potential in SO_2 eq
Eutrophication	Eutrophication potential in PO_4^{3-} eq
Photochemical ozone formation	Photochemical Ozone Creation Potential POCP in NMVOC eq
Ozone depletion	ODP in R11 eq
Ionising radiation	Ionising radiation potentials in U235 eq
Particulate matter	Particulate matter formation in PM2.5 eq
Human toxicity, cancer and non-cancer	Comparative Toxic Unit for Human Health in CTUh
Ecotoxicity, freshwater	Comparative Toxic Unit for ecosystems in CTUe
Resource depletion – minerals and metals	ADP ultimate reserves in Sb eq
Resource depletion – fossil energy carriers	ADP fossil in MJ
Land use	Land occupation in $m^2 * a$
Water scarcity	Scarcity-adjusted water use in m^3

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Table recreated from Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA, Ricardo Energy and Environment (Link)

LIFECYCLE INVENTORY ANALYSIS (LCI)

Lifecycle Inventory Analysis (LCI)

Definitions

- **ISO 14040 definition**
- LCI is the phase of lifecycle assessment involving the compilation and quantification of *inputs* and *outputs* for a product throughout it's lifecycle.

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- *Inputs* and *outputs* are product, material or energy flows that enter or leave a *unit process.*
- A *Unit Process* is the smallest element considered in the life-cycle inventory analyis for which input and output data are quantified.

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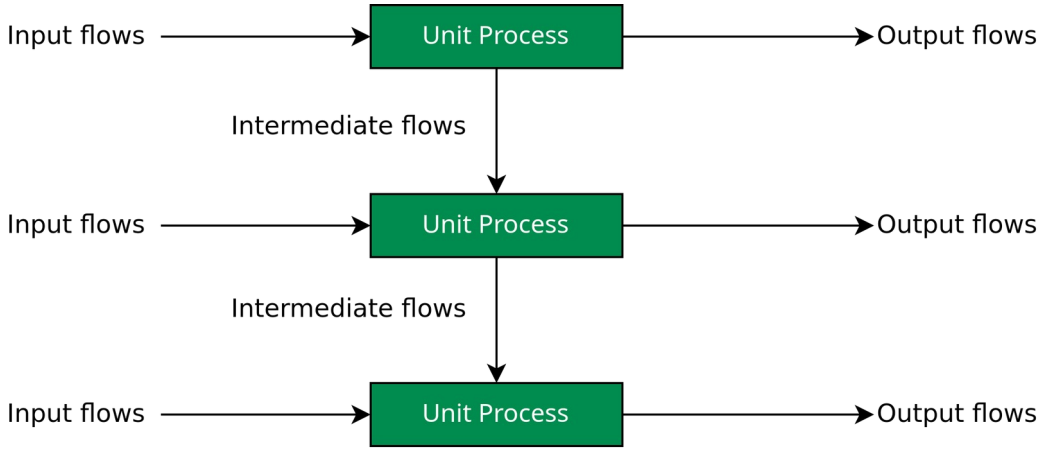
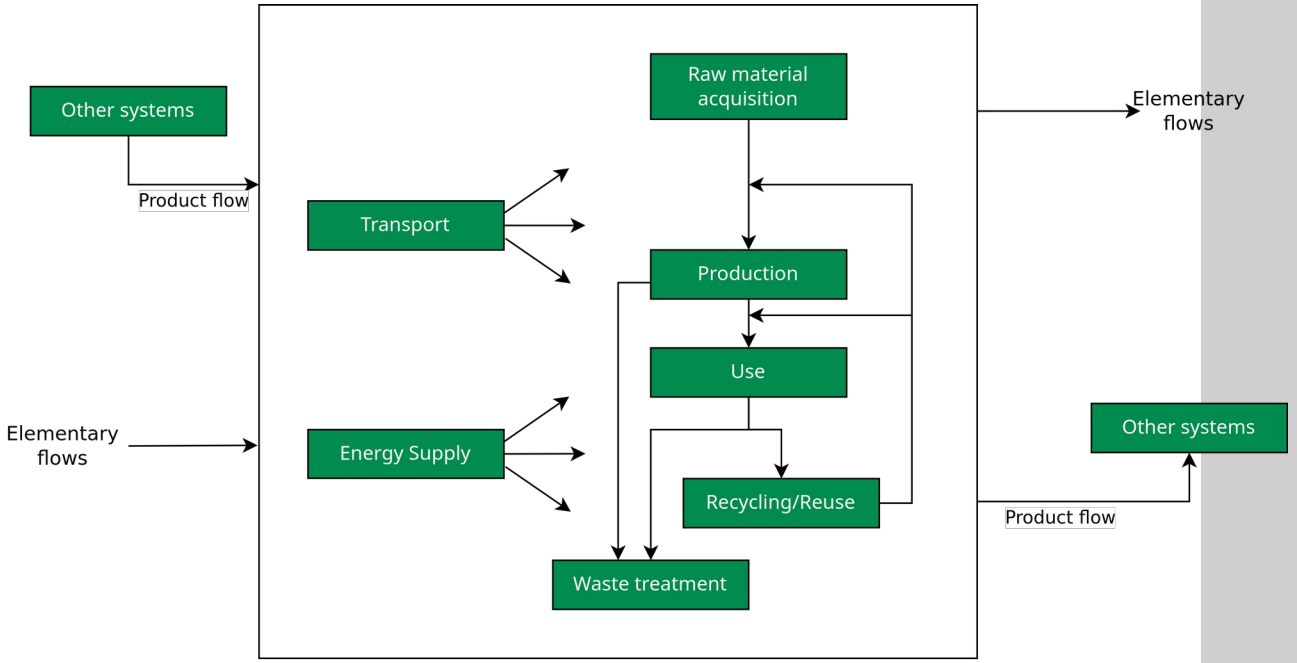
Lifecycle Inventory Analysis (LCI)



Example of a set of unit processes within a product system



Example of a product system

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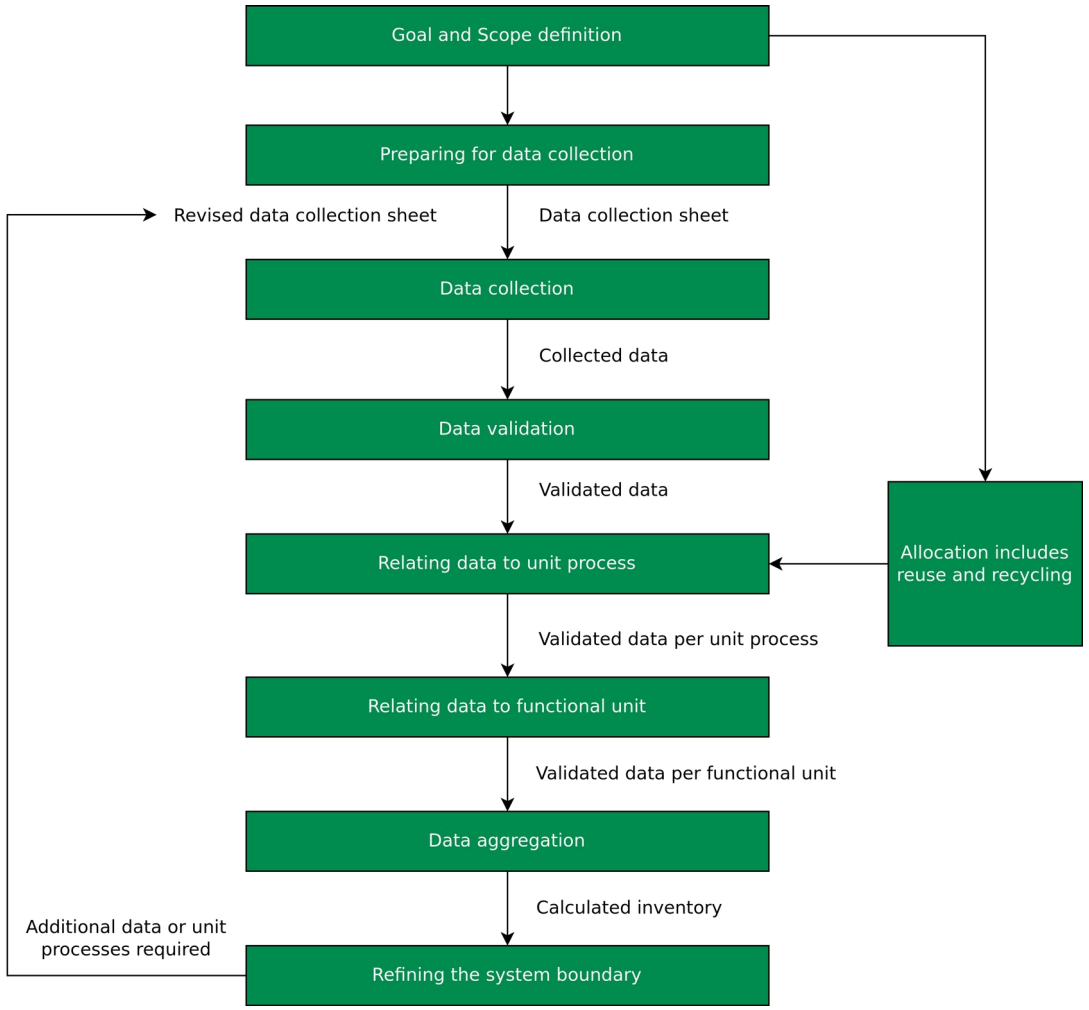
Lifecycle Inventory Analysis (LCI)

Overview



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Lifecycle Inventory Analysis (LCI)

Preparing for data collection

Completed by:	Date of completion:			
Unit process identification:	Reporting location:			
Time period: Year	Starting month:	Ending month:		
Description of unit process:				
Material inputs	Units	Quantity	Description of sampling procedures	Origin
...	...	...	...	...
Water consumption	Units	Quantity		
...	...	...	...	...
Energy Inputs	Units	Quantity	Description of sampling procedures	Origin
...	...	...	...	...
Material outputs	Units	Quantity	Description of sampling procedures	Destination
...	...	...	...	...

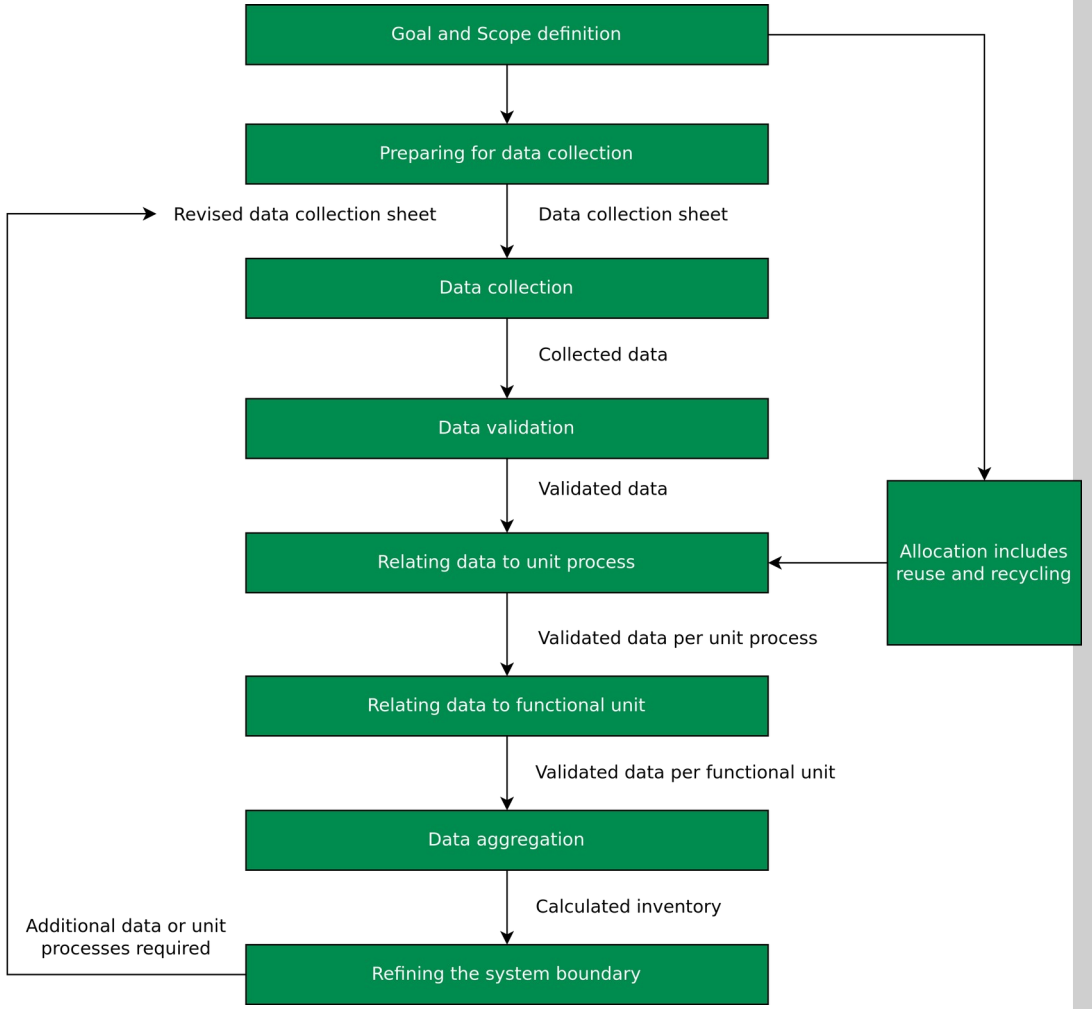
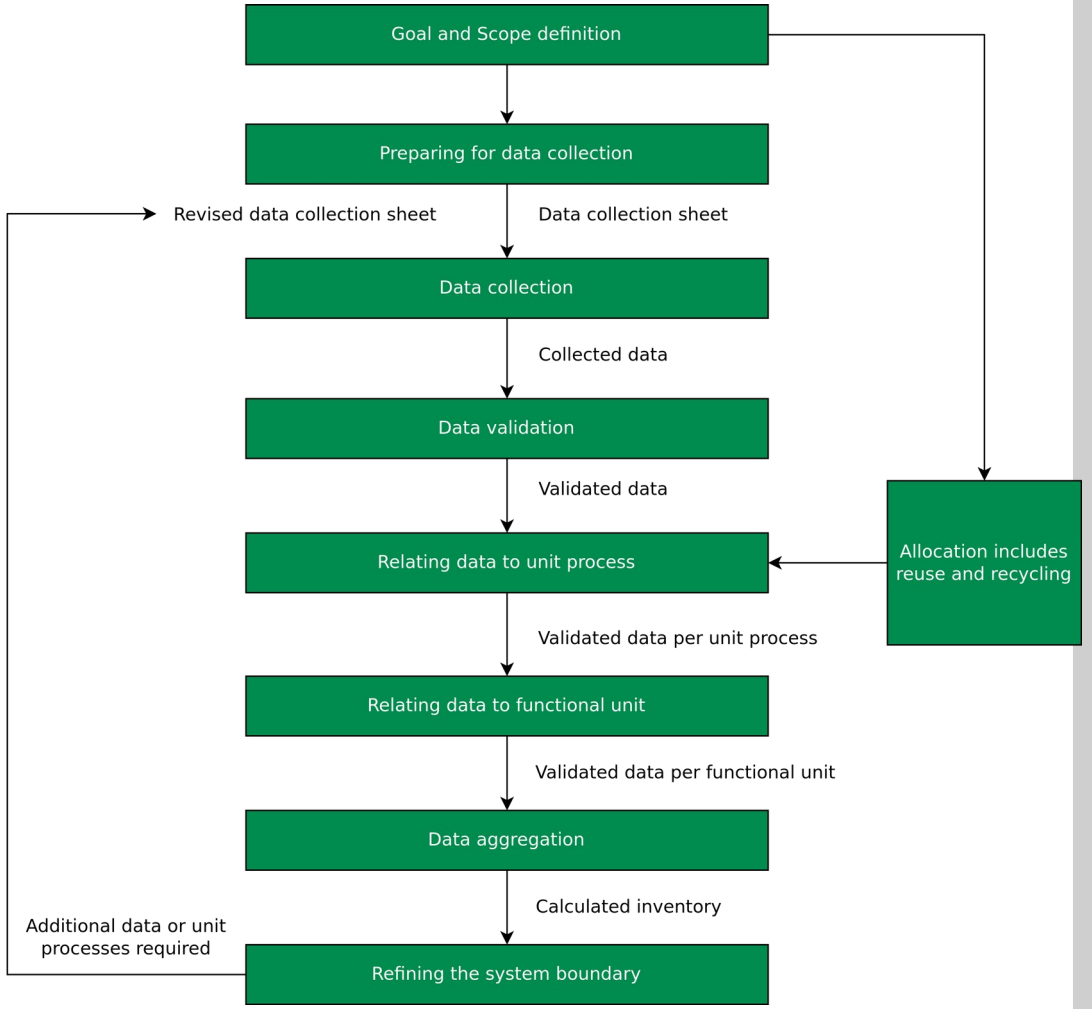


Image and table recreated from ISO 14040 Environmental management — Life cycle assessment — Principles and framework, International standards organisation (https://www.iso.org/standard/37456.html)

Lifecycle Inventory Analysis (LCI)

Data collection and validation

- Data must be validated to confirm and provide evidence for data quality requirements, both during and after the data collection process.
- This can also involve establishing mass and energy balances.
- Obvious anomalies can necessitate collecting alternative data.



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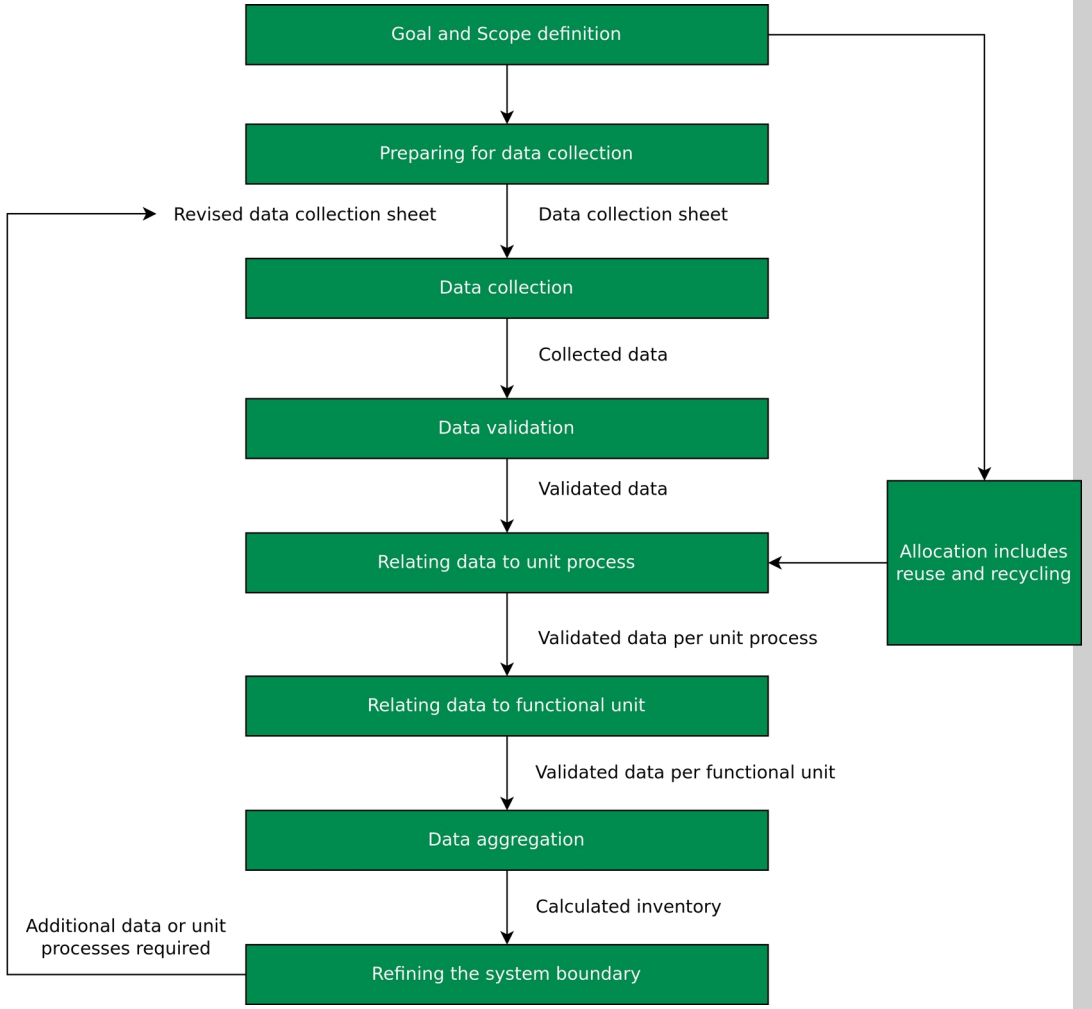
Lifecycle Inventory Analysis (LCI)

Relating data to unit process and functional unit

- Based on the flow chart and the flows between unit processes, the flows of all unit processes are related to the reference flow.
- The calculation should result in all system input and output data being referenced to the functional unit.
- *Recall:* the reference flow is a measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit.

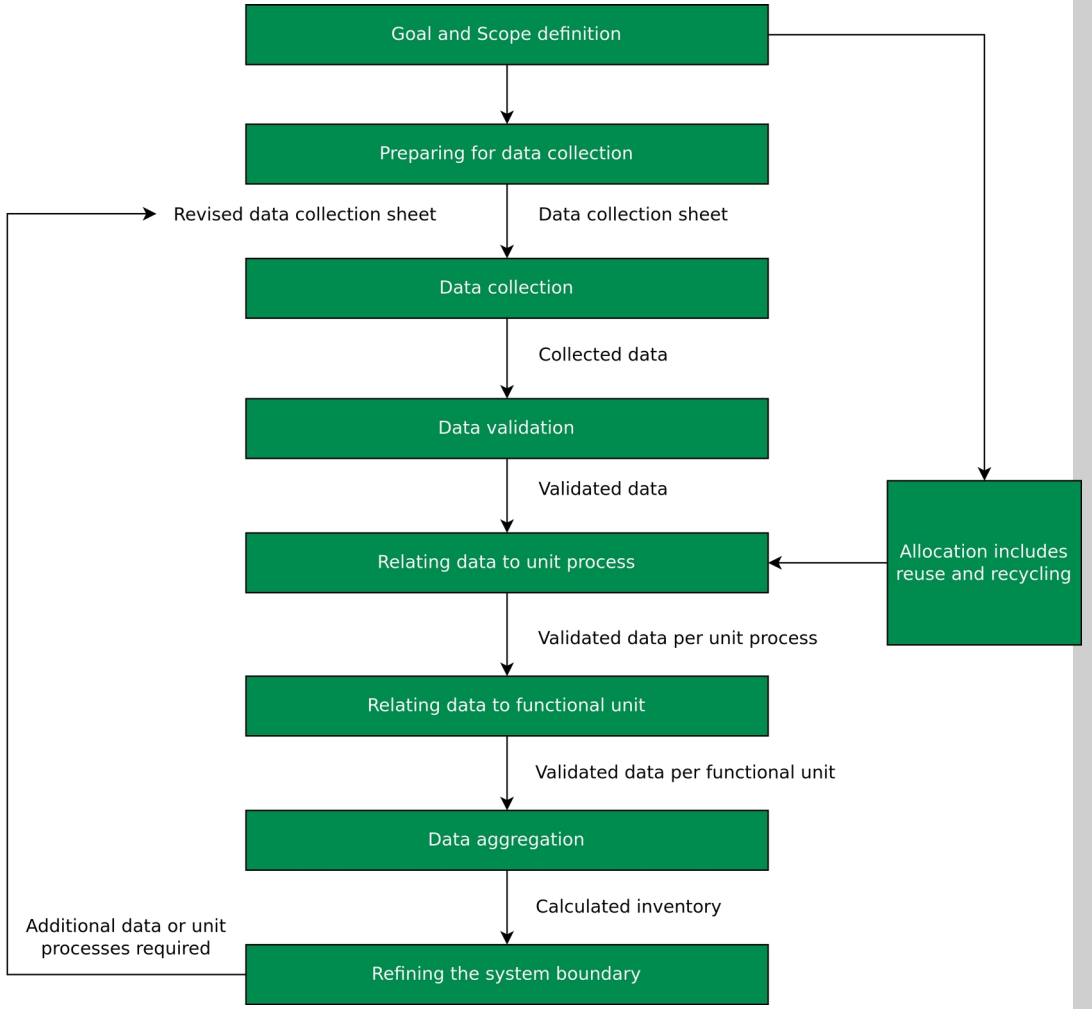


ISO 14040 Environmental management — Life cycle assessment — Principles and framework, International standards organisation (https://www.iso.org/standard/37456.html)

Lifecycle Inventory Analysis (LCI)

Relating data to unit process and functional unit

- In the example of a truck, a specific transport scenario would be defined in the study that uses the data set for the specific truck used, ensuring again a clear identification and quantification.
- E.g. the transport scenario “150 km overland transport of bulk sand transport at 90 % load factor” with the quantity and unit of e.g. 1 t*km and the data set “Truck bulk transport; Euro 0, 1, 2, 3, 4 transport mix; 22 t total weight, 17.3 t max payload”.



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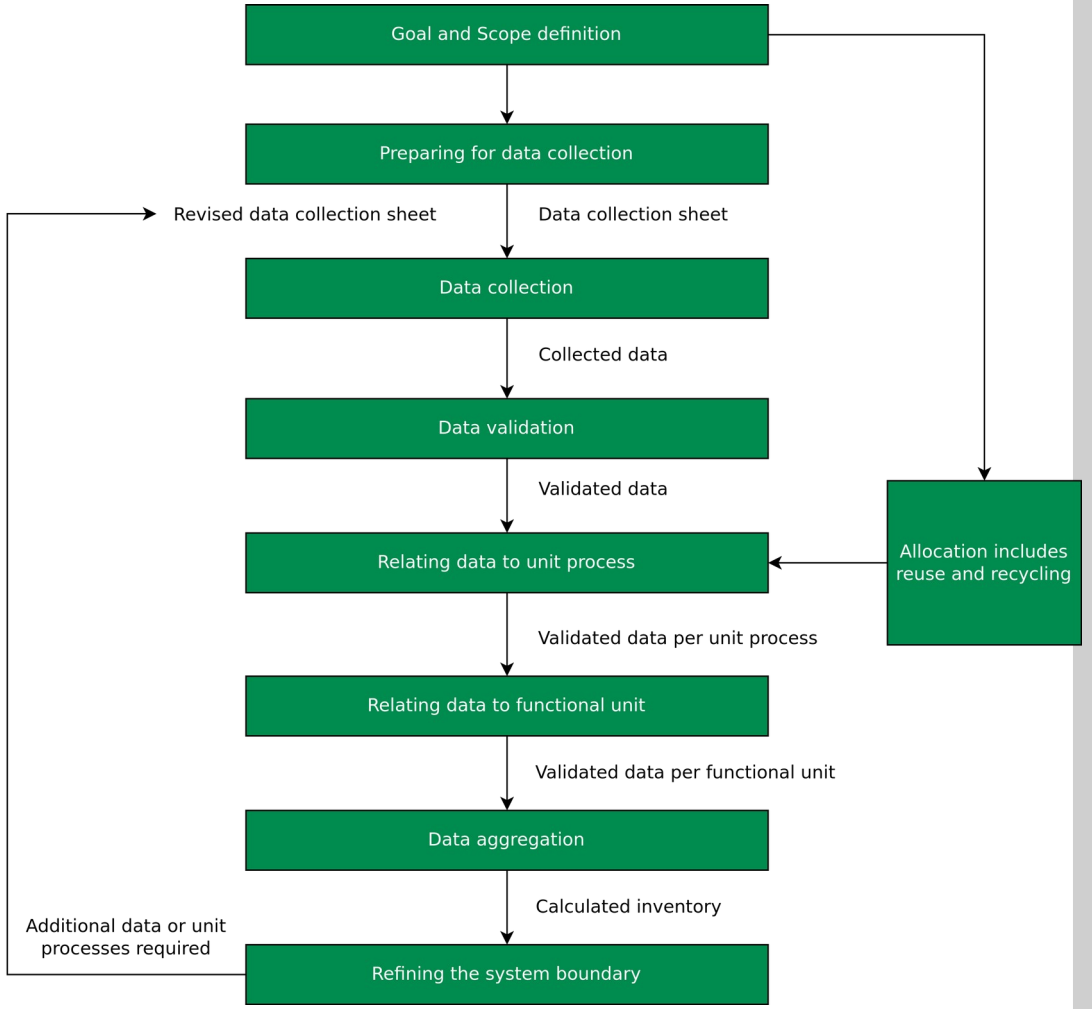
Lifecycle Inventory Analysis (LCI)

Refining the system boundary

- The initial system boundary is revised, in accordance with the cut-off criteria established before.
- Further analysis may result in:
  - Exclusion of life cycle stages or unit processes if they lack significance
  - Exclusion of inputs or outputs
  - Inclusion of new unit processes, inputs and outputs that are shown to be more significant than estimated before.



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Lifecycle Impact Assessment (LCIA)

Definition

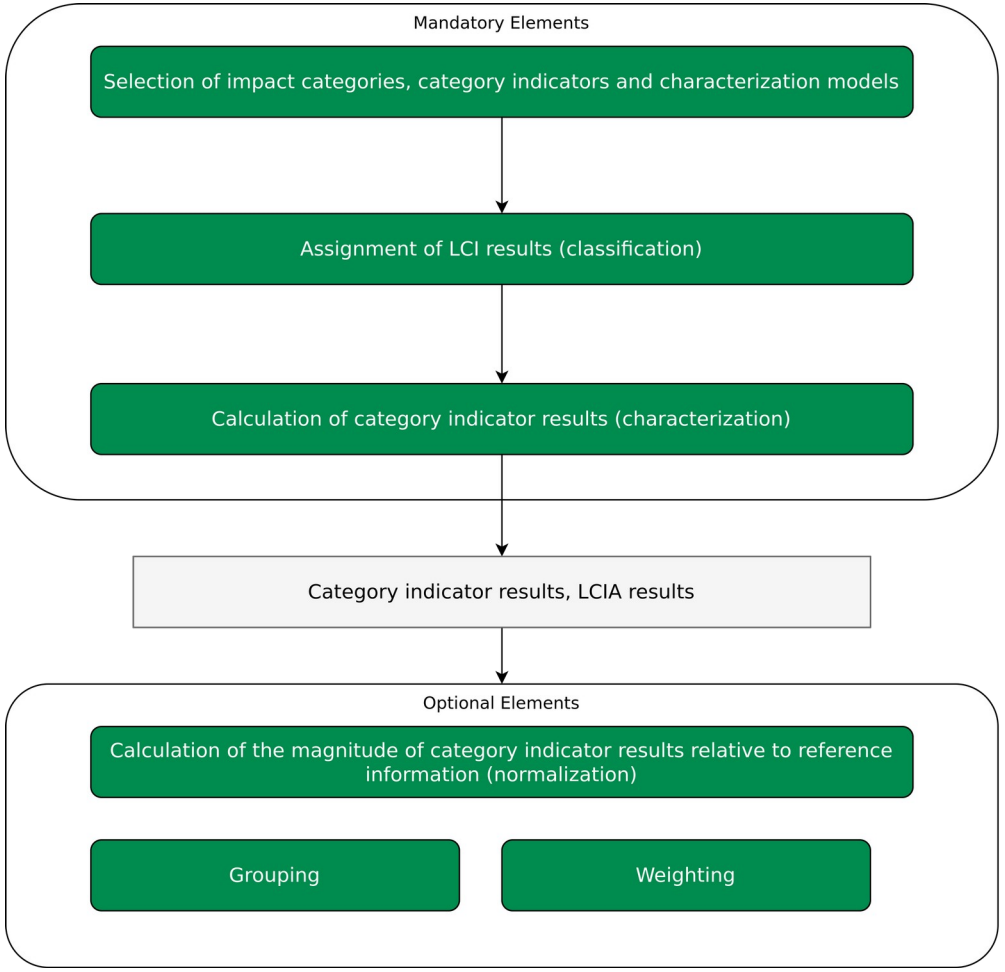
- **ISO 14040 definition**
- The phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product.

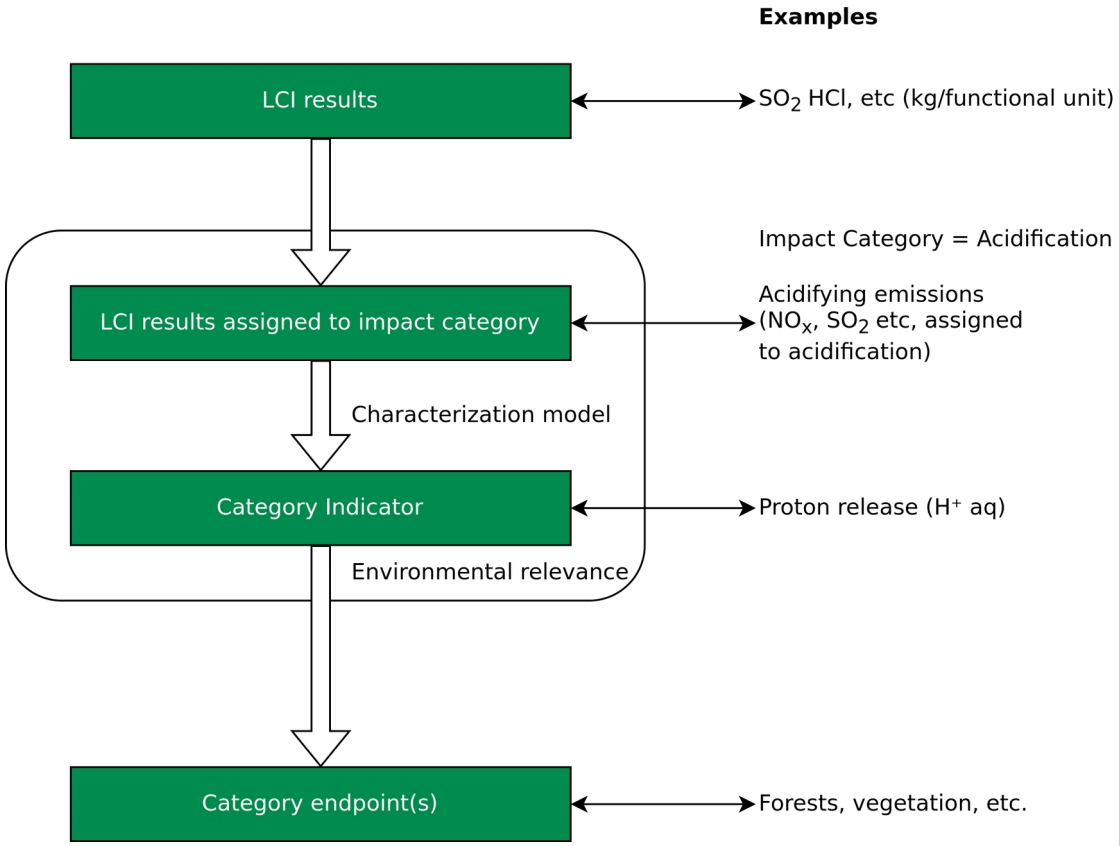
ISO 14040 Environmental management — Life cycle assessment — Principles and framework, International standards organisation (https://www.iso.org/standard/37456.html)

Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA, Ricardo Energy and Environment (Link)

Lifecycle Impact Assessment (LCIA)

Elements of LCIA





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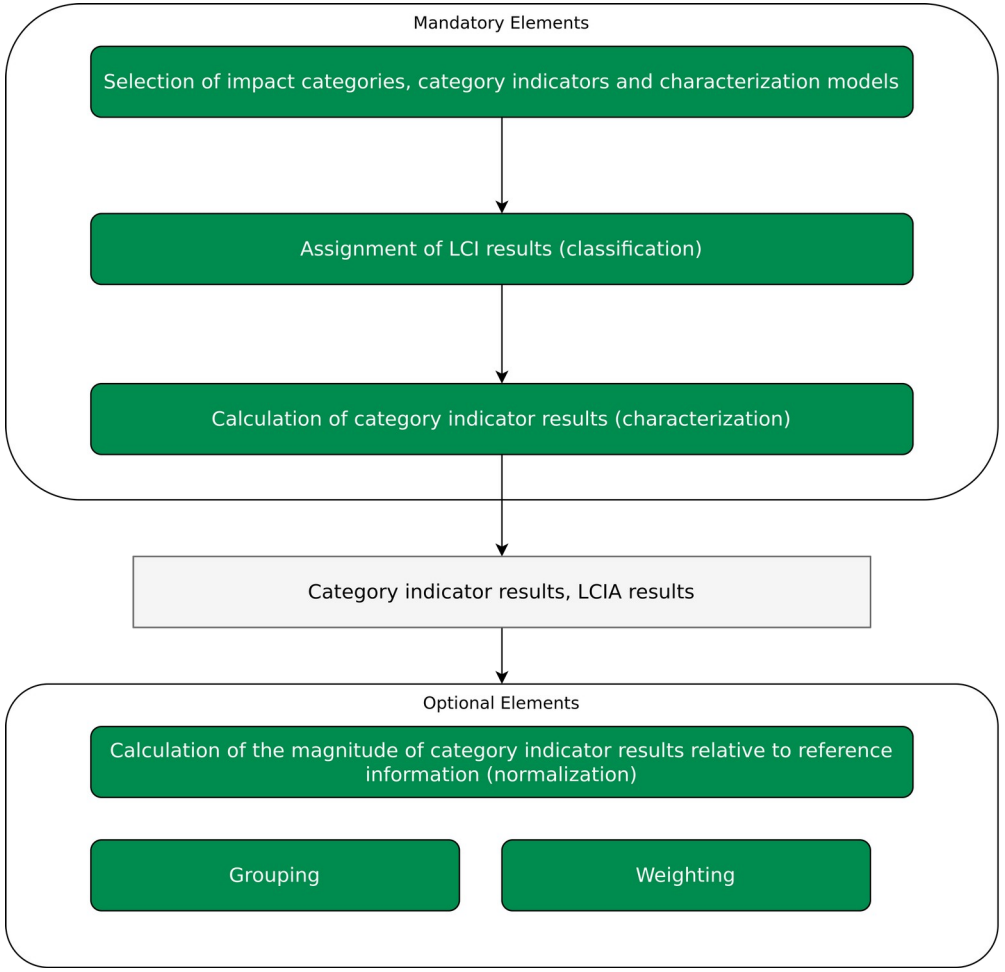

Term	Example
Impact Category	Climate change
LCI results	Amount of a greenhouse gas per functional unit
Characterization model	Baseline model of 100 years of the Intergovernmental Panel on Climate Change
Category indicator	Infrared radiative forcing (W/m²)
Charecterization factor	Global warming potential (GWP_{100}) for each greenhouse gas (kg CO_2–equivalents/ kg of gas)
Category indicator result	Kilograms of CO_2–equivalents per functional unit
Category endpoints	Coral reefs, forests, crops
Environmental relevance	Infrared radiative forcing is a proxy for potential effects on the climate, depending on the integrated atmospheric heat adsorption caused by emissions and the distribution over time of the heat adsorption.

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Resource depletion – fossil energy carriers	ADP fossil in MJ
Land use	Land occupation in $m^2 * a$
Water scarcity	Scarcity-adjusted water use in m^3

Pollutant	Acidification	Eutrophication	POCP	Particulate matter formation (PMF)
CO	0	• 0	0.0456	0
NH_3	1.6	0.35	0	0.64
NO_x	0.5	0.13	1	0.88
$PM_{2.5}$	0	0	0	1
SO_x	1	0	0.0811	0.54
NMVOC	0	0	1	0.012

Non-methane volatile organic compoind

Tables recreated from Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA, Ricardo Energy and Environment (Link)

Lifecycle Impact Assessment (LCIA)

Example

Summary of overall lifecycle GWP impacts for Lower Medium Cars for different powertrain types (Baseline scenario for 2020, 2030 and 2050. Tech1.5 scenario for 2050)

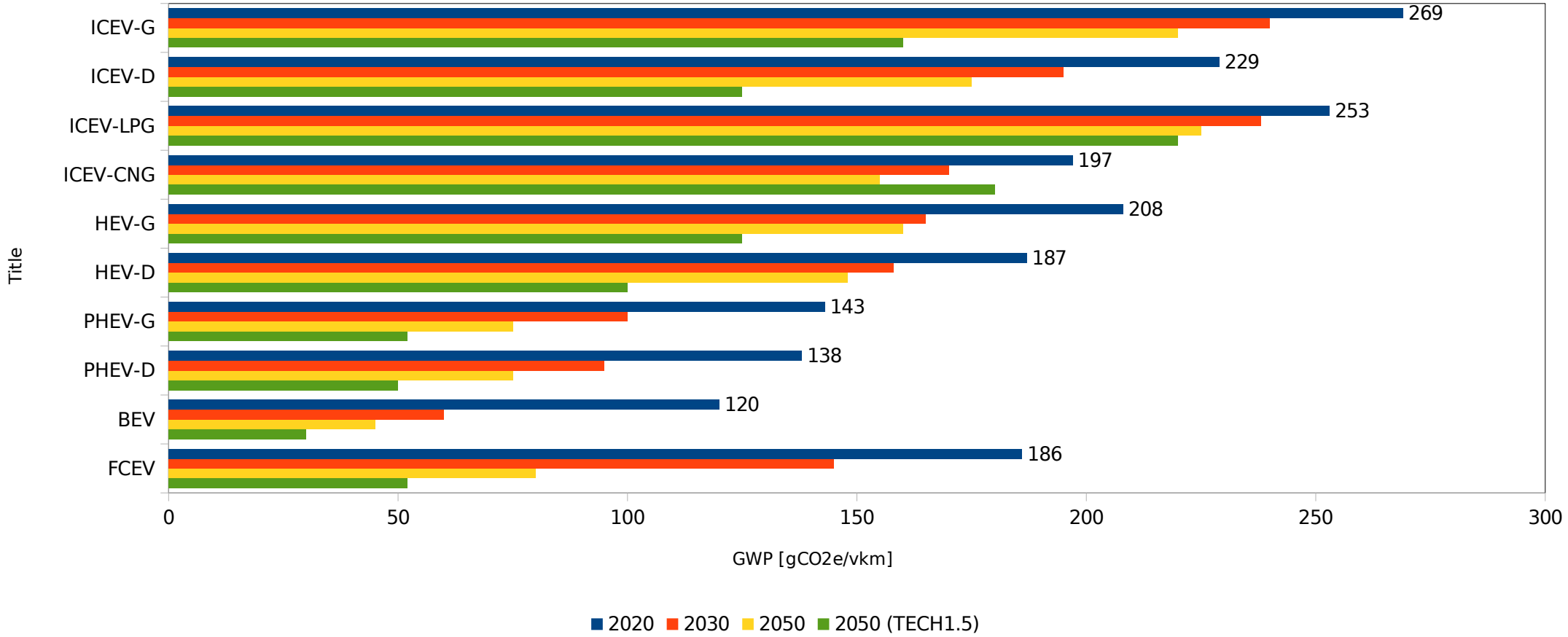


Chart adapted from Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA, Ricardo Energy and Environment (Link)

Lifecycle Interpretation

Definition

- **ISO 14040 definition**
- The phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations.

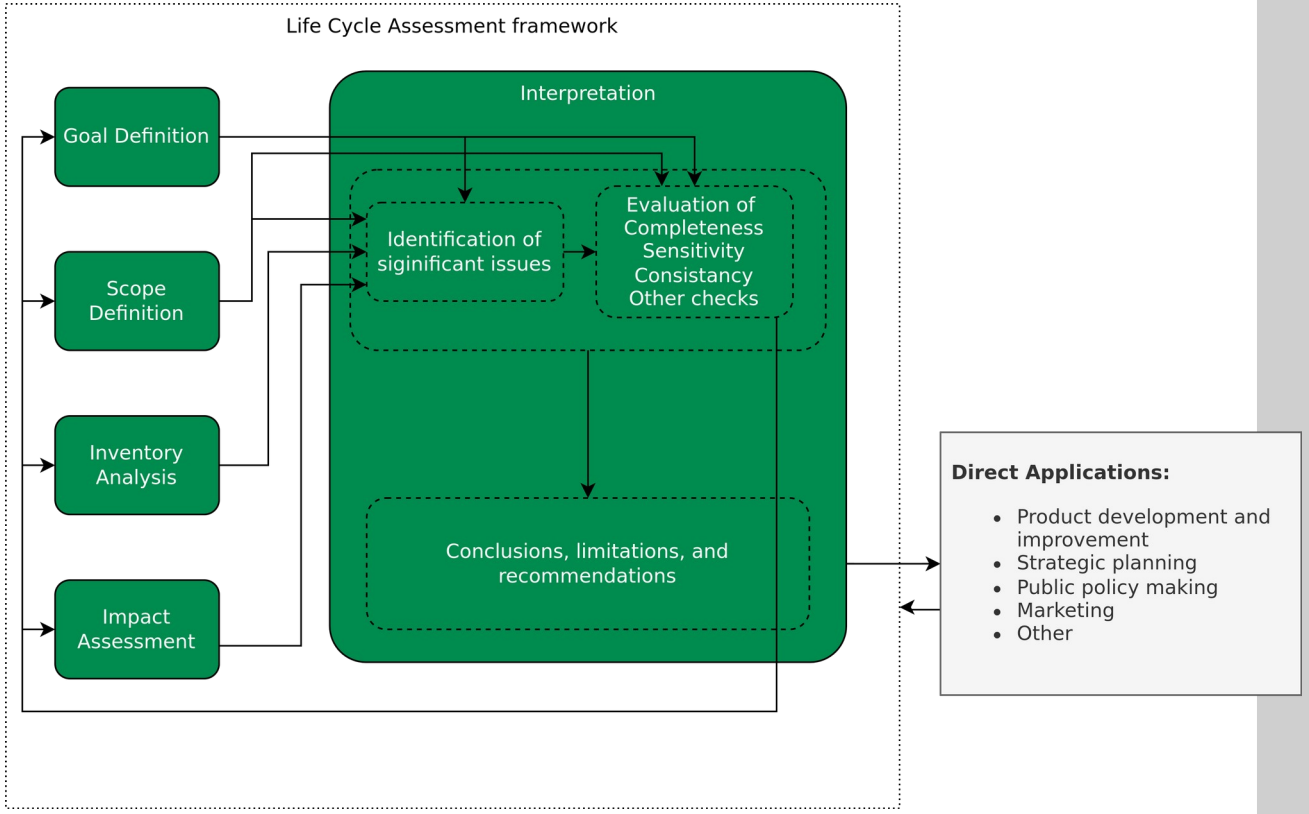
ISO 14040 Environmental management — Life cycle assessment — Principles and framework, International standards organisation (https://www.iso.org/standard/37456.html)

Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA, Ricardo Energy and Environment (Link)

Lifecycle Interpretation

Identification of significant issues

- Two interrelated aspects of significant issues:
  - The main contributors to environmental impacts, like most important lifecycle stages, processes and elementary flows.
  - The main choices that have the potential to influence the precision of the final results of the LCA, like methodological choices (e.g., cut-offs), assumptions, data, LCIA methods.



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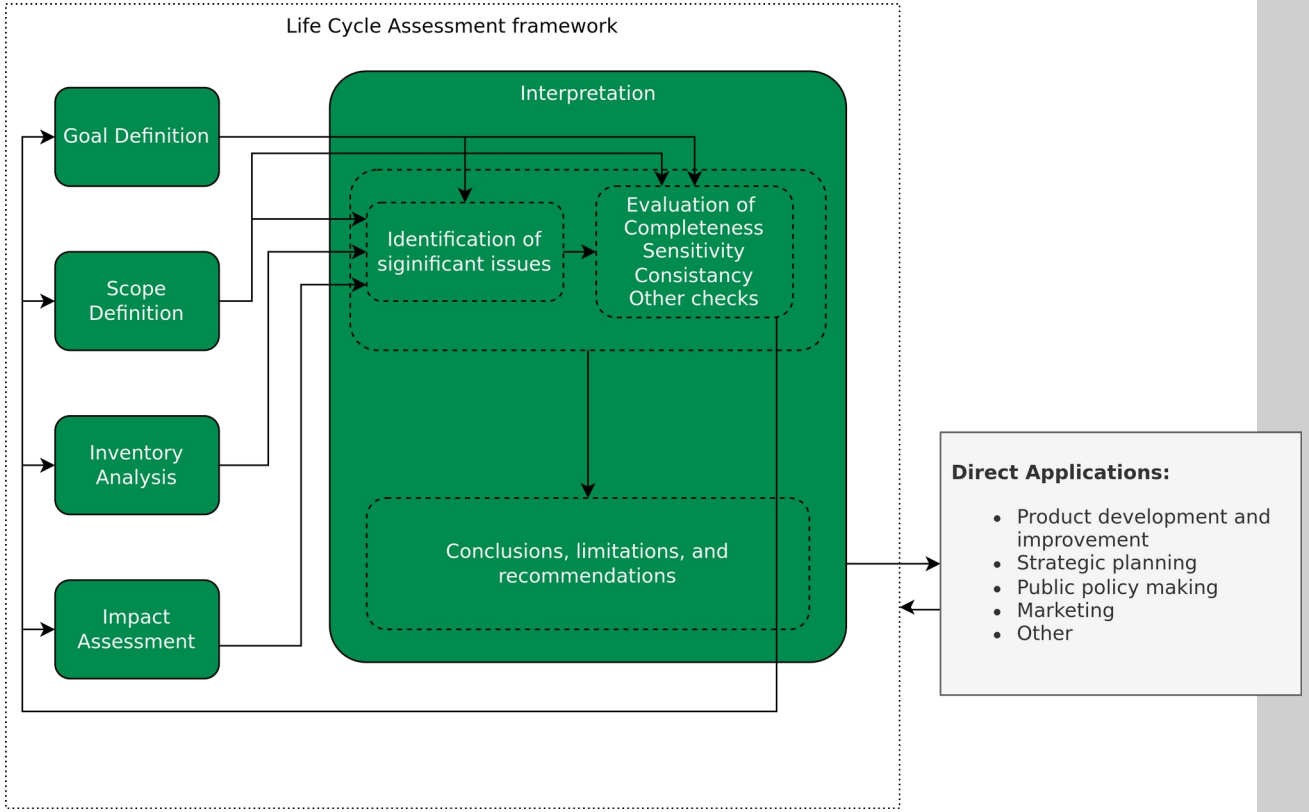
Lifecycle Interpretation

Evaluation

- Evaluation is performed to establish the foundation for subsequently drawing the conclusions and provide reccommendations during the interpretation of the study results.
- This involves:
  - Completeness checks
  - Sensitivity checks in combination with scenario analysis and potentially uncertainity analysis
  - Consistancy checks



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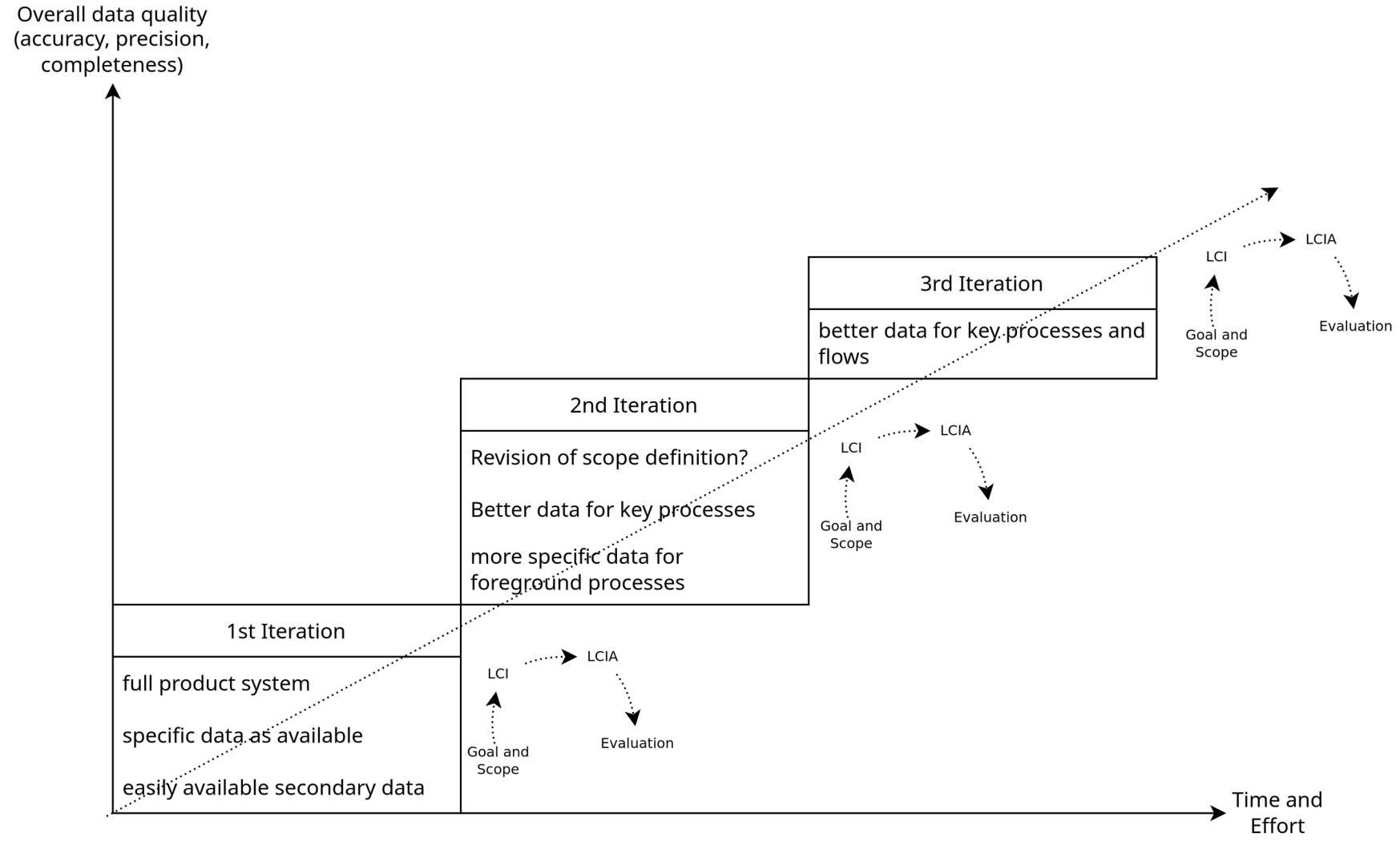
Iterative Approach to LCA



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Reporting and Critical Review

- A reporting strategy is an integral part of an LCA.
- A report should:
  - contain the results and conclusions of the LCA in an adequate form to the intended audience
  - address the data, methods and assumptions applied in the study, and the limitations thereof.

ISO 14040 Environmental management — Life cycle assessment — Principles and framework, International standards organisation (https://www.iso.org/standard/37456.html)

Reporting and Critical Review

- A reporting strategy is an integral part of an LCA.
- A report should:
  - contain the results and conclusions of the LCA in an adequate form to the intended audience
  - address the data, methods and assumptions applied in the study, and the limitations thereof.
- A critical review will fascilitate understanding and enhance the credibility of the LCA.
- Critical reviews verify whether the LCA has met the requirements for methodology, data, interpretation and reporting and whether it is consistant with it’s principles.
  - Carried out by an internal or external expert, or by a panel of interested parties.

ISO 14040 Environmental management — Life cycle assessment — Principles and framework, International standards organisation (https://www.iso.org/standard/37456.html)

CONCLUSION

Conclusion

- A high-level overview and guide to Life Cycle Assessment
  - Goal and Scope definition
  - Life Cycle Inventory analysis
    - Unit Processes and Process flows
  - Life Cycle Impact Assessment
    - Impact categories, classification, characterization, weighting, etc.
  - Life Cycle Interpretation
    - Evaluation
    - Reporting and Critical review
- Examples from Polestar and the 2020 EU Commission report.

EXERCISE E04

Exercise E04

My Favorite Fruit/Vegetable – LCA using OpenLCA

- With the fruit/vegetable you chose in E03, and the information you gathered, compute the Environmental Impact of the product system, including:
  - Production of the fruit/vegetable
  - Transport of the fruit/vegetable to the place you bought it from
  - ..
- You can use the automated tools provided in OpenLCA to do this easily, using the free datasets provided on OpenLCA Nexus.

- Suggested detailed tutorial: Link
- QnA session tutorial will also be available via Github.
- Default option → potato

- Use an existing LCIA methodology, such as BEES+.
- Submit your submission according to the instructions in the exercise sheet.

Questions?