Life Cycle Assessment: Introduction

February 2023

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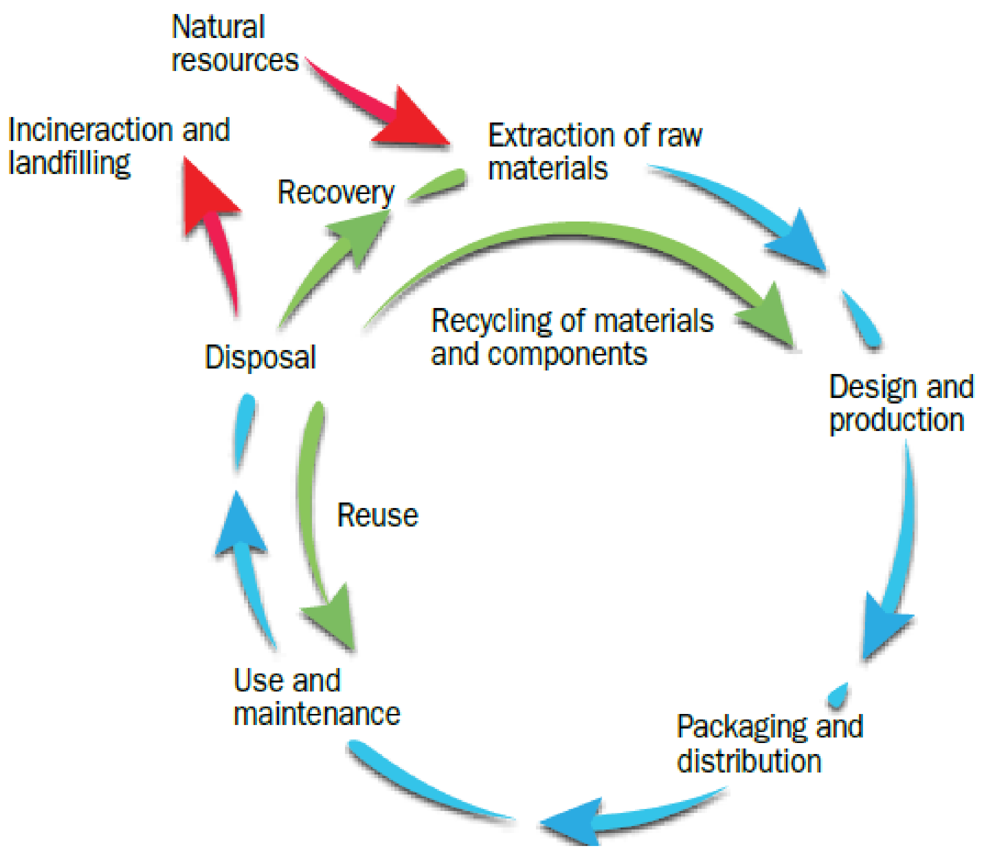
Project Scope

- Conduct LCAs for all existing and emerging VT energy sources
  - Fossil fuels, biofuels, renewables, hydro, other fuels in imported electricity
- Focuses on Greenhouse Gases
- Uses publicly available data for transparency in calculations
- Incorporates stakeholder input

What is Life Cycle Assessment (LCA)?

International Organization for Standards definition: LCA is the "**compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle**."

Per ISO 14040



International Council of Chemical Associations. 2013. How to Know If and When it's Time to Commission a Life Cycle Assessment. Figure 1.

LCA Benefits and Limitations

Benefits:

- Quantifies activity pollutants and related environmental impacts
- Serves as a decision aid
  - Best to conduct *before* decision-making process
  - Use in conjunction with other decision-making tools
- Helps avoid unintended consequences, and balance tradeoffs

Limitations:

- Constrained by available data and level of detail
- Do not always produce clear decision pathways
  - Other complimentary methods needed

Stakeholder Input

- Aim: gather and understand stakeholder perspectives to help guide current LCA and shape a framework for subsequent energy pathways work
- Holding two stakeholder meetings
  - Inform parties of expected energy pathways for current analysis and gather input for potential incorporation
  - Energy sources and pathway considerations beyond GHGs
- Input used to inform
  - Current GHG-focused analysis
  - Scoping document for future work that examines other impact categories
- Requesting support from Just Transitions subcommittee
  - Stakeholder identification and engagement
  - Meeting design and content

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APPENDIX
Additional Information: Conducting an LCA

Benefits of LCA

- LCAs can be used to quantify amounts of pollutants associated with certain activities across supply chains (ex. manufacturing, electricity production, transportation) and estimate their corresponding environmental impacts (ex. climate change, land use, biodiversity loss, etc.)
  - They have been adapted to other impact categories such as employment, human health, etc.
- It is best to conduct LCAs *before* decisions are made; use LCA as one (of possibly multiple) decision-making tools
  - Can compare choices with quantified metrics – environmental ‘nutrition’ label
  - Can be used to identify major contributors to impact at a high level and focus improvement efforts
- LCAs can be used to avoid unintended consequences, and balance tradeoffs

Limitations of LCA

- LCAs are constrained by available data
  - Can see mismatches in temporal, geographical, technological representativeness
  - Responsibility of the LCA practitioner to replicate the conditions of the studied system to the best of their ability in the model
- LCAs are constrained by their level of detail
  - Datasets feeding into LCAs often are average data for certain activities (ex. statistical biodiversity loss from pollutants emitted)
  - Other methods of study (ex. location-specific environmental risk assessment) are necessary to compliment LCAs

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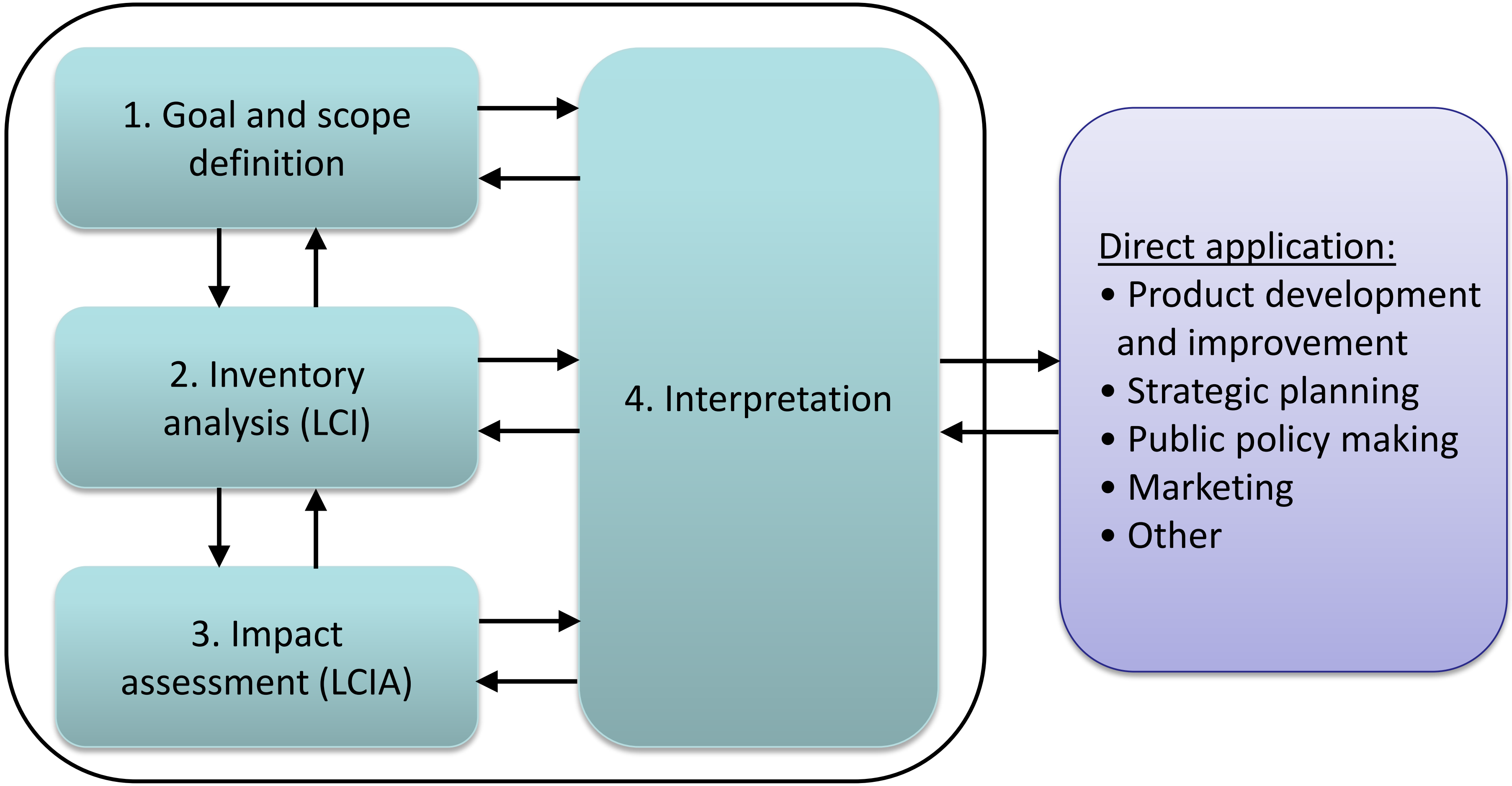
Limitations of LCA, Continued

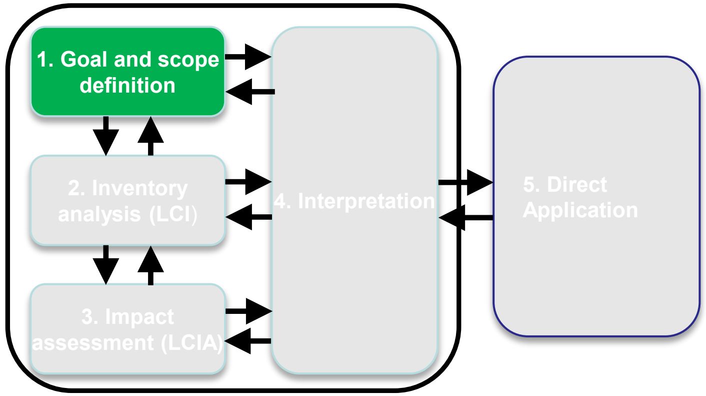
- LCAs do not always produce clear decision pathways
  - Decision makers and communities may face results which favor one choice with, for example, quantified greenhouse gas benefits, but at large costs to ecosystems and human health
  - Responsibility of communities to understand all tradeoffs and weigh impact categories

How do you conduct an LCA?



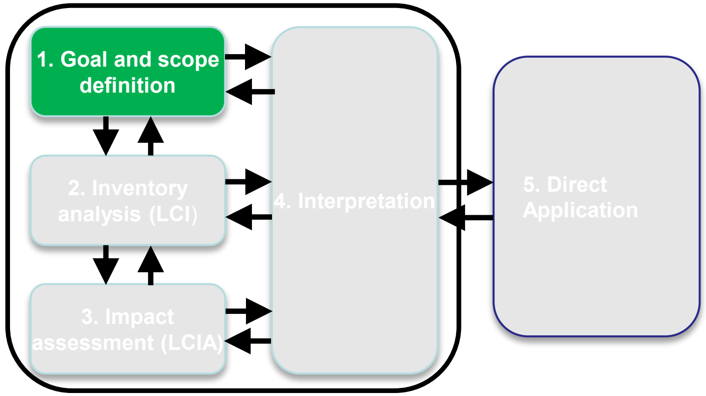
Phase 1: Goal and Scope

1. Frame out the project so it will meet goals and objectives
   - What is the purpose of the study?
     - To generate life cycle data for all energy pathways used by, or that are emerging, in the state of Vermont to inform decisions in pursuit of goals set by the Vermont 2020 Global Warming Solutions Act (GWSA)
   - Who is the intended audience?
     - Policy and decision makers; community members impacted by, or involved in energy projects; etc.
   - How will the results be used?
     - To understand historical greenhouse gas impacts of, and inform decisions for, energy pathways in Vermont



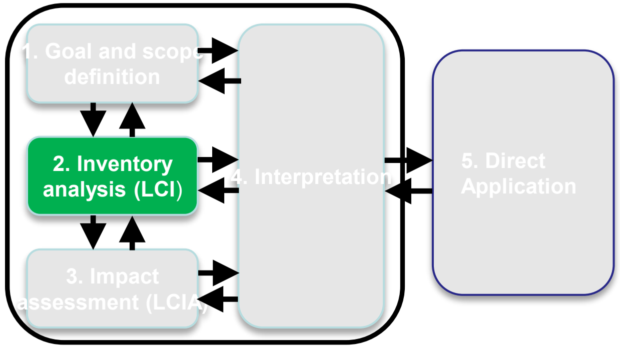
Phase 1: Goal and Scope, Continued

2. Set Project Scope to Meet Project Goals
   - Functional Unit
     - One unit of energy generated by each energy pathway
     - A means for comparing energy pathways on an equal basis
   - System Boundaries
     - Entire life cycles of energy pathways
       - Fossil fuels: Cradle (extraction from the Earth) to combustion and use
       - Renewables: Cradle to combustion/waste management
   - Life Cycle Stages
     - Extraction, processing, transportation/transmission, storage, use, waste management



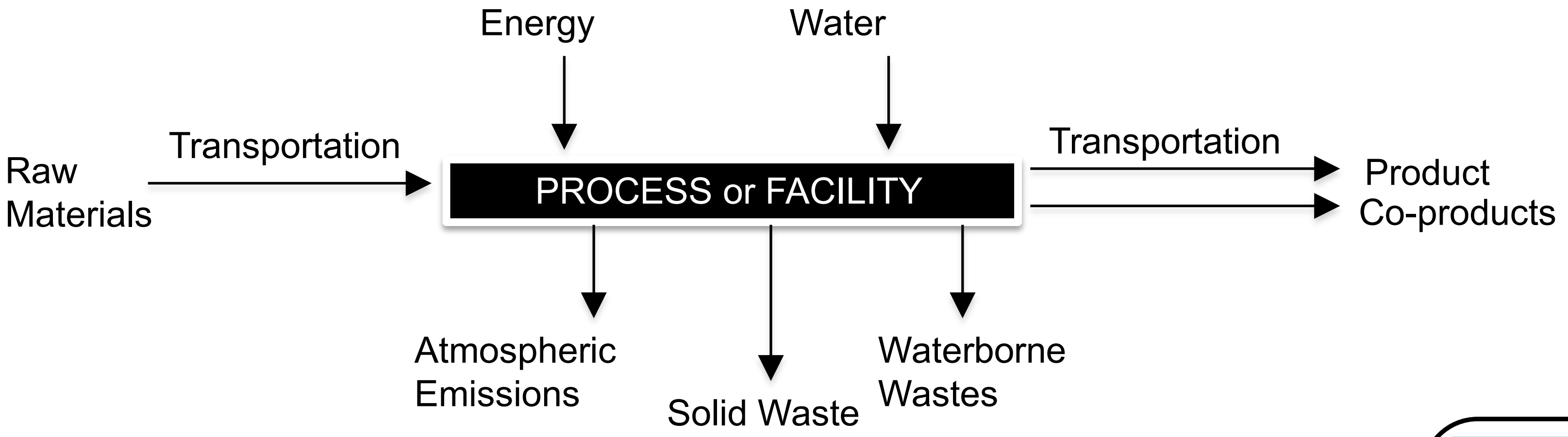
Phase 2: Life Cycle Inventory

- The life cycle inventory (LCI) is the basic documentation process on which the LCA is built.
- LCI produces a quantified list of the inputs and outputs of raw materials, energy, and releases to the air, water, and land over the complete life cycle of a product system.

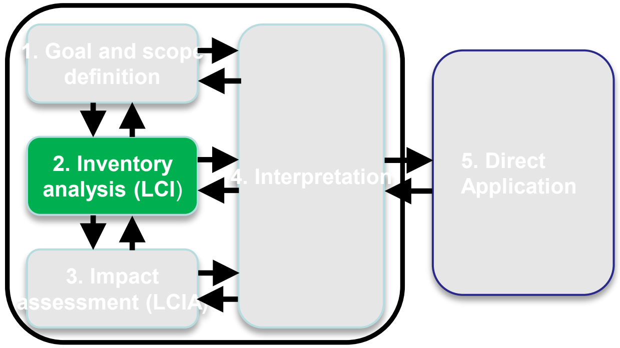


Build Unit Processes

- Using the life cycle flow diagram, develop data on a unit process basis for each step

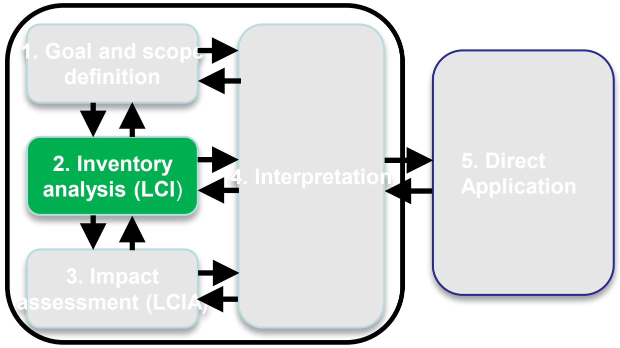


- Link each process to the related upstream and downstream processes, including production and combustion of fuels used



Types/Sources of LCI Data

- Data collected from facilities (primary)
- Published reports and statistics (secondary)
  - Peer-reviewed journal articles
  - Industry reports
  - U.S. government data series
  - Other publicly available life cycle studies
- Databases (publicly available or licensed)
  - U.S. LCI Database (www.nrel.gov/lci); Federal LCA Commons (https://www.lcacommons.gov/)
  - International databases (e.g., ecoinvent)
  - Databases in LCA software (e.g., openLCA, SimaPro, GaBi)



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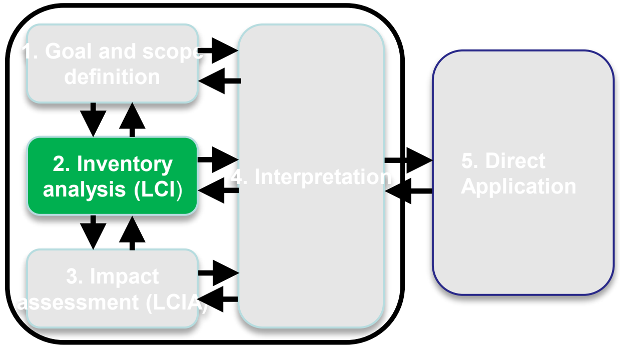
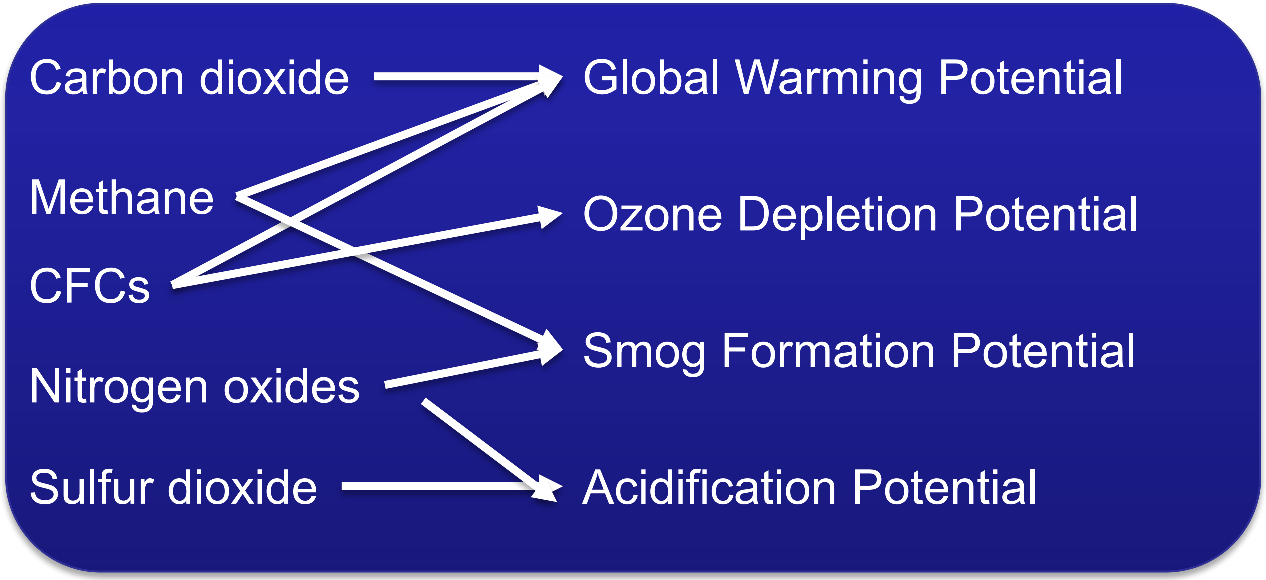
Life Cycle Inventory Results

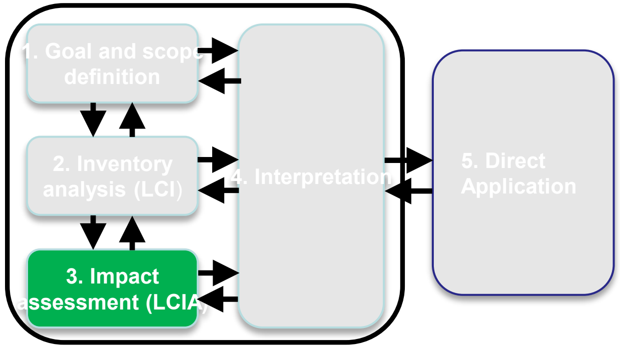
- Quantified inventory of flows to/from the environment for each system studied:
  - Raw materials, including water
  - Energy use
  - Solid wastes
  - Atmospheric emissions
  - Waterborne emissions
- Can draw some conclusions from LCI, but emissions results can be difficult to interpret – many diverse emissions, mixed results



Phase 3: Impact Assessment (LCIA)

- How can you interpret complex mix of emissions results in a meaningful way?
- **1. Classification:** group emissions into categories where they may contribute to environmental or human health impacts





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Impact Assessment Steps

2. Characterization: normalize within each category to common reference substance, e.g., CO_2 equivalents for global warming potential

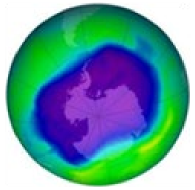
Acidification Potential [kg SO_2 eq]

Eutrophication Potential [kg N eq]

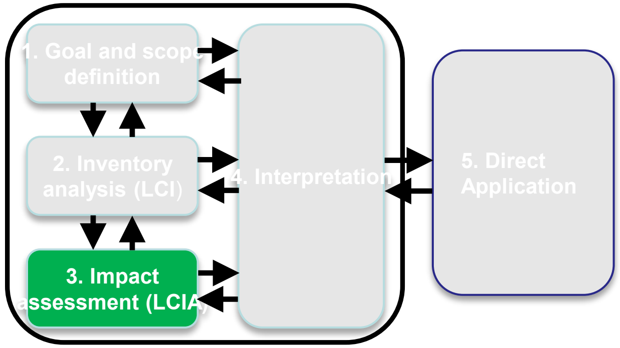
Human Health, Carcinogens [CTUh]

Global Warming Potential [kg CO_2 eq]

Ozone Depletion Potential [kg CFC-11 eq]



Smog Formation Potential [kg O_3 eq]

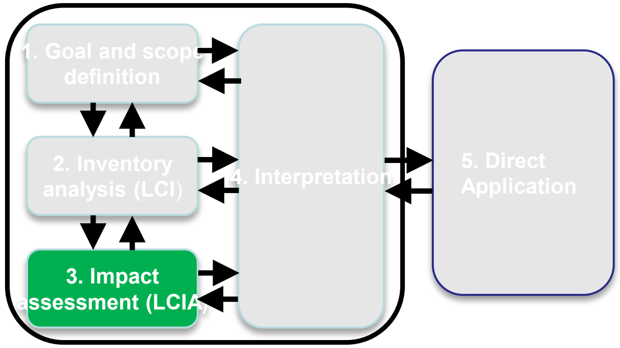


- Results are **potential** impacts, not absolute or precise impacts

Existing Life Cycle Impact Assessment Methods

IPCC global warming potential over a 100-year time horizon

Substance	AR1 (1990)	AR2 (1995)	AR3 (2001)	AR4 (2007)	AR5 (2013)
Carbon dioxide, fossil (CO_2)	1	1	1	1	1
Methane, fossil (CH_4)	21	21	23	25	28
Methane, biogenic (CH_4)	18.25	18.25	20.25	22.25	25.25
Dinitrogen monoxide (N_2O)	290	310	296	298	265
HCFC-141b	440	-	700	725	782
HFC-134a	1200	1300	1300	1430	1300
HCFC-22	1500	-	1700	1810	1760
HCFC-142b	1600	-	2400	2310	1980
CFC-11	3500	-	4600	4750	4660
CFC-12	7300	-	10600	10900	10200
Sulfur hexafluoride	-	23900	22200	22800	23500



Source: IPCC AR1-AR5, Table from: https://www.pre-sustainability.com/news/updated-carbon-footprint-calculation-factors (Accessed 1/28/19)

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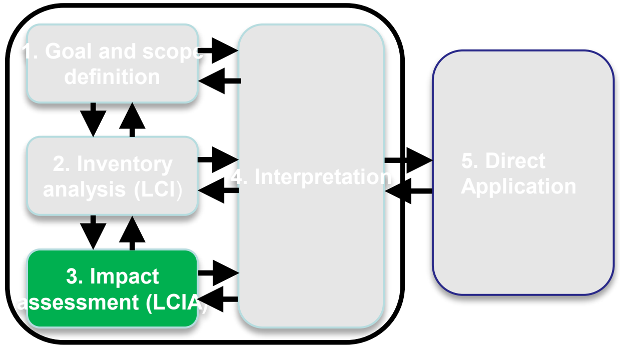
Existing Life Cycle Impact Assessment Methods

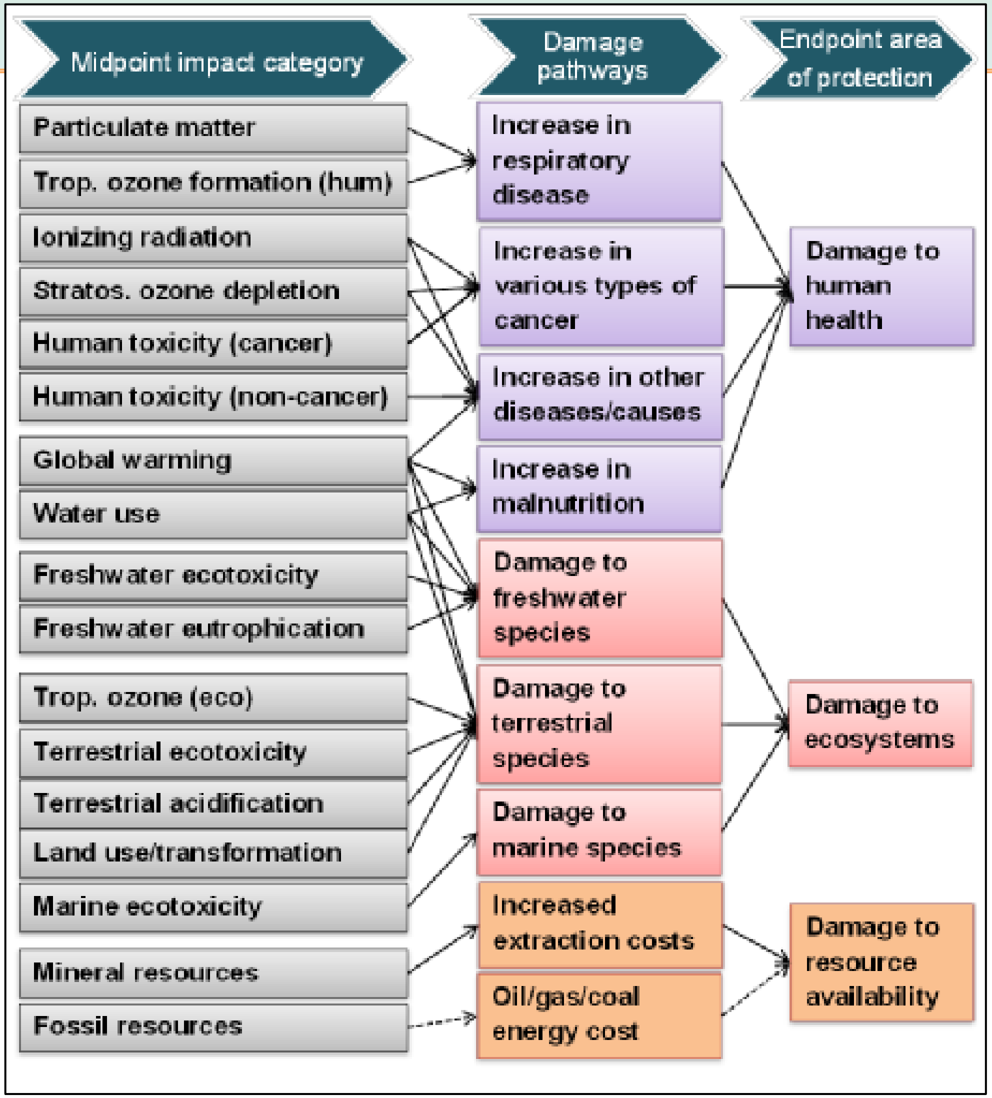
Examples (In addition to IPCC)

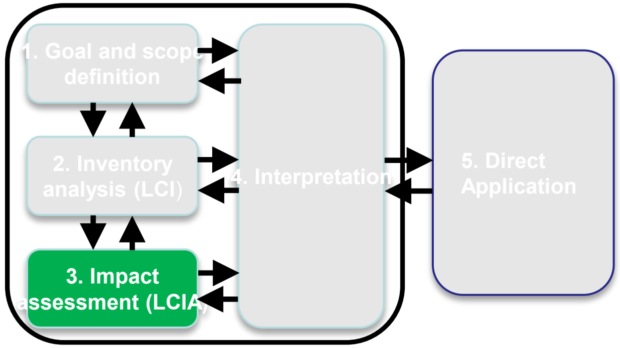
- U.S. EPA's Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI): https://www.epa.gov/chemical-research/tool-reduction-and-assessment-chemicals-and-other-environmental-impacts-traci
- The Global ReCiPe model (18 midpoint indicators, 3 endpoint indicators): https://www.rivm.nl/en/life-cycle-assessment-lca/recipe
- Water Scarcity: the AWARE method (Available Water Remaining), https://wulca-waterlca.org/aware/what-is-aware/
- Human and Eco-Toxicity: USETox, https://usetox.org/



From Midpoint to Endpoint

- ReCiPe example units:
  - Human Health (disability-adjusted life years, DALY)
  - Ecosystems (species.yr)
  - Resources availability (dollars)



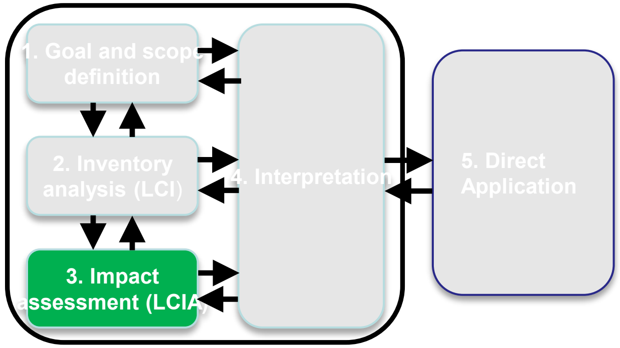


Source: From RIVM, the Dutch National Institute for Public Health and the Environment https://www.rivm.nl/en/life-cycle-assessment-lca/recipe

Impact Assessment Limitations

1. Characterization factors are based on certain fate and transport pathways

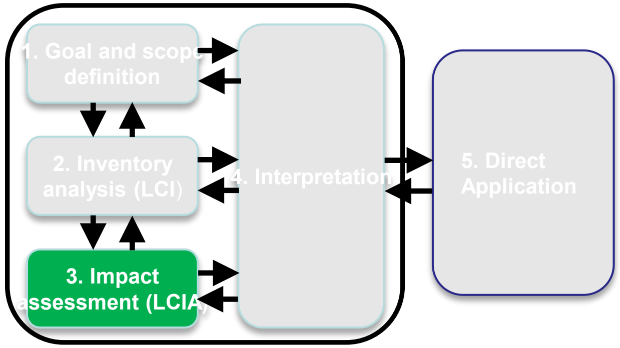
- No transparency on where emission ends up: land, sea, organism?
- No differentiation between exposures: inhaled, ingested, skin contact?
- May vary by region or country



Impact Assessment Limitations

2. Aggregated life cycle inventory emissions can represent two very different scenarios with different impacts with similar results

1. Single concentrated release with direct human exposure
2. Sum of multiple small releases occurring at different locations over different periods of time



Phase 4: Interpretation

- **Tools of Interpretation/Analysis:**
  - **Contribution analysis:** What are the main processes/materials contributing to results?
  - **Sensitivity analysis:** Test sensitivity of results to changes in factors such as product weight, allocation and recycling methodology, end of life management
  - **Tradeoff analysis:** Do improvements in one impact category lead to increased burdens in another?
  - **Observations and conclusions**