BUREK LAB | BUilding REsilience through Knowledge



SCAN ME

Life Cycle Assessment (LCA)

Unlocking Low-Carbon Solutions for a Sustainable Energy Future

UMASS LOWELL

CWEEL webinar, June 5th, 2024

About us

Andrea Boero

- BSc Mechanical Engineering, ESPOL, Ecuador
- MSc Energy Conversion and Management, University of Nottingham, UK
- PhD student, UMass Lowell

www.linkedin.com/in/andrea-boero-b1b1a120

www.linkedin.com/in/mahsaghandi

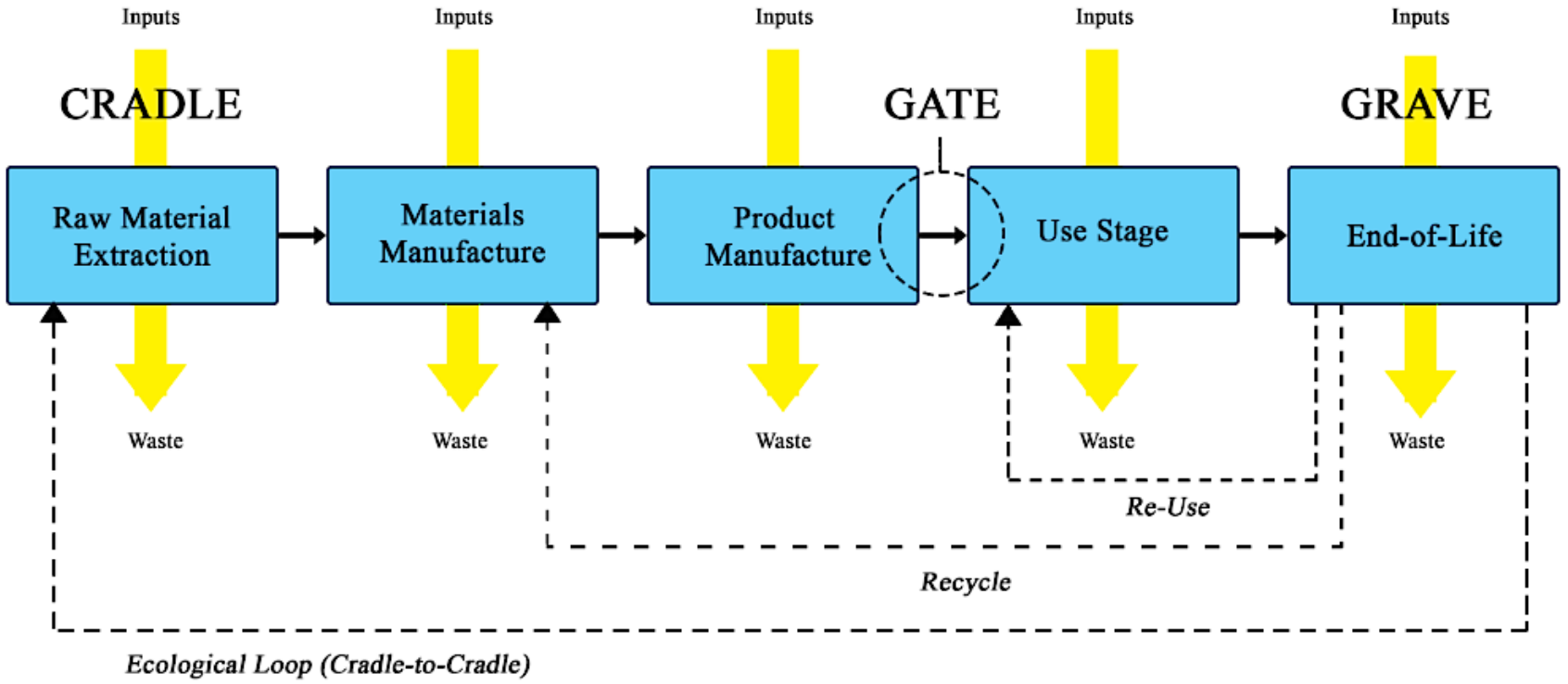
Mahsa Ghandi

- BSc, Civil-Water engineering, University of Tehran, Iran
- MSc. Water Resources engineering,University of Tehran, Iran
- PhD student,Department of Mechanical and Industrial Eng, University of Massachusetts Lowell

UMASS LOWELL
Learning with Purpose

What is LCA?

Life Cycle Assessment (LCA): systematic method used to evaluate the environmental impacts of a product, process, or service throughout its entire life cycle.



Purpose: Identifies opportunities for reducing environmental footprints and improving sustainability.

History of LCA

Early Beginnings

- 1960s: The concept of analyzing the environmental impact of products emerged, initially focusing on energy consumption and waste generation.
- 1970s: The first LCA studies were conducted, primarily in the packaging industry, leading to the development of the Coca-Cola Company's study on beverage containers.

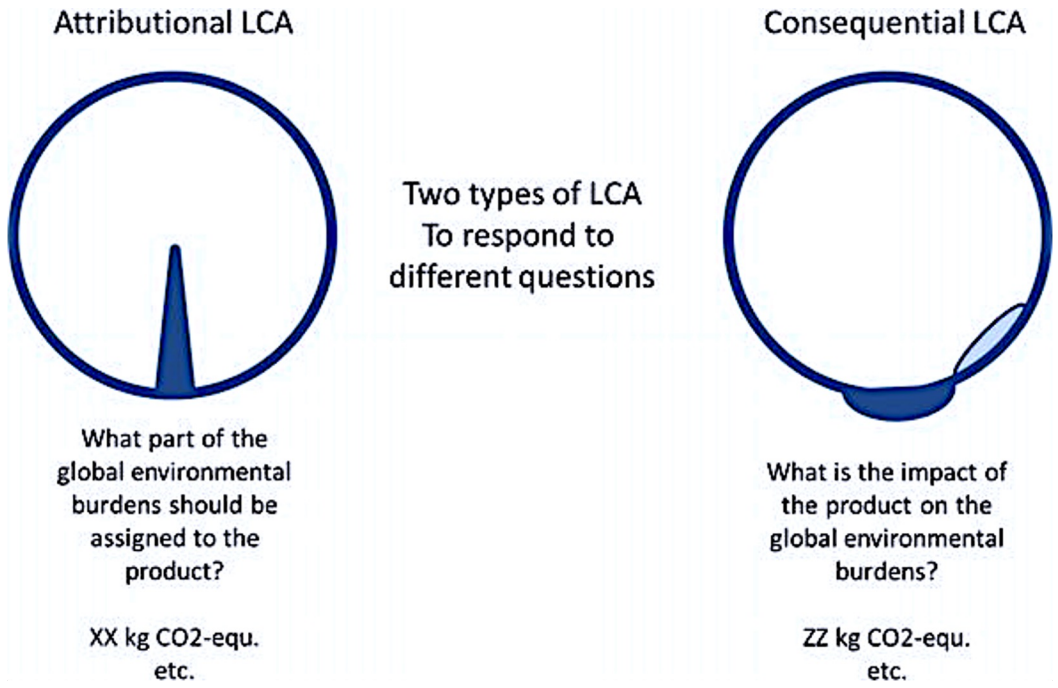
History of LCA

Evolution and Standardization

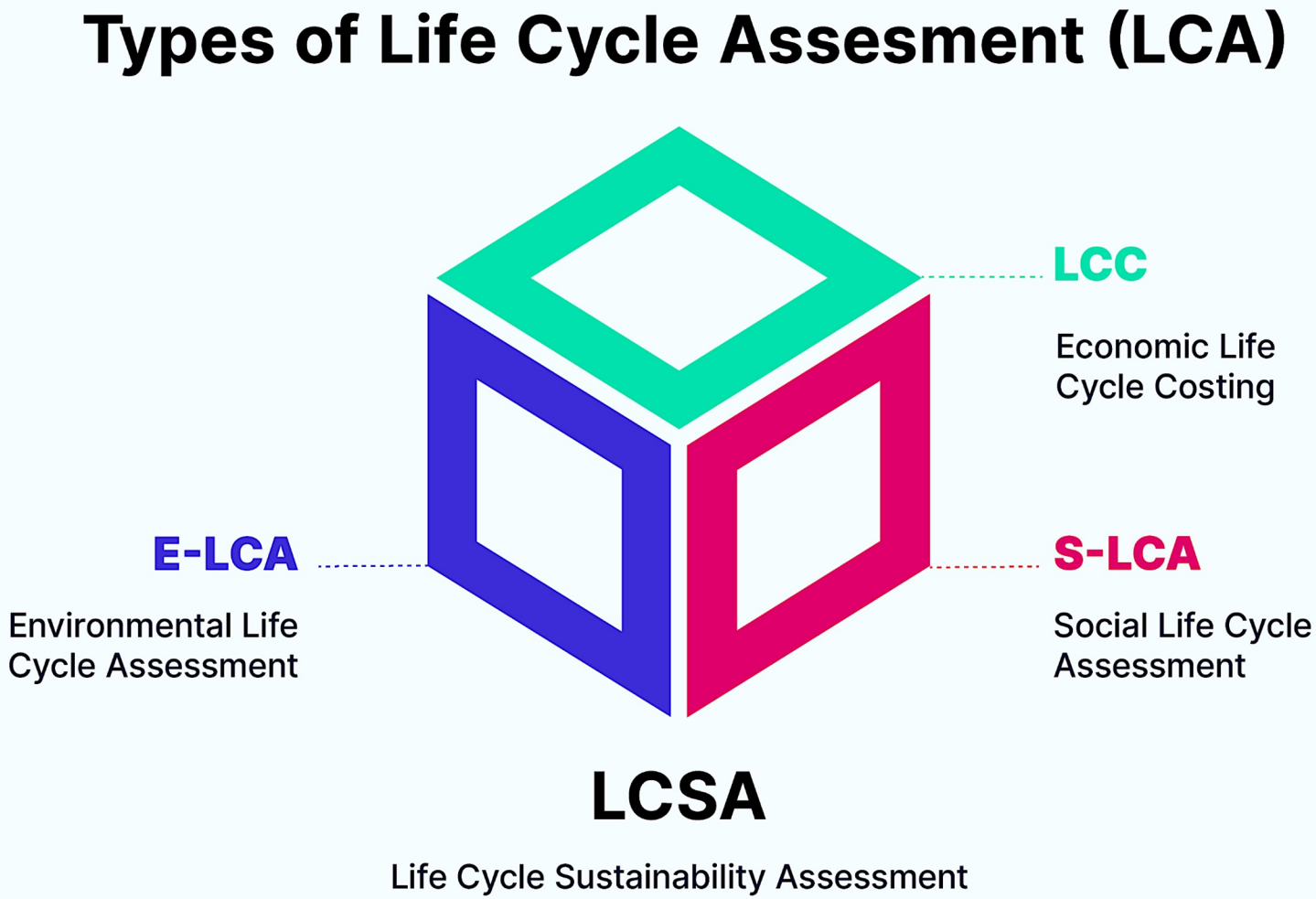
- 1990s: The International Organization for Standardization (ISO) developed standardized guidelines for conducting LCAs (ISO 14040 series).
- 2000s and Beyond: LCA became more sophisticated with advancements in software tools, databases, and methodologies. It expanded to various industries, including construction, automotive, electronics, and energy sectors.

Traditional Types of LCA

- Attributional LCA (aLCA)
- Consequential LCA (cLCA)
- Screening LCA
- Simplified LCA
- Streamlined LCA



Life Cycle Sustainability Assessment (LCSA)



Application of LCA

Manufacturing and Product Design

Example: Eco-friendly packaging materials.

Why: Reduce waste and improve sustainability.

Energy Sector

Example: Comparing fossil fuels and renewable energy sources.

Why: Identify sustainable energy solutions.

Construction and Building Design

Example: Green building materials.

Why: Promote sustainable construction.

Automotive Industry

Example: Electric vehicles vs. internal combustion engines.

Why: Support low-emission transportation.

Agriculture and Food Industry

Example: Carbon footprint of farming practices.

Why: Promote sustainable agriculture.

Waste Management

Example: Recycling vs. landfill impacts.

Why: Develop eco-friendly waste strategies.

Who Uses LCA

- Corporations
- Governments and Policymakers
- Researchers and Academics
- Non-Governmental Organizations (NGOs)
- Consultants

Why is LCA Used

Identify Environmental Hotspots

Enhance Sustainability

Regulatory Compliance and Certification

Informed Decision-Making

Strengthen Brand Reputation

Engage with Your Carbon Footprint

CoolCalifornia Carbon Footprint Calculator

Estimate your carbon footprint based on household activities.

Enter personal and household information.

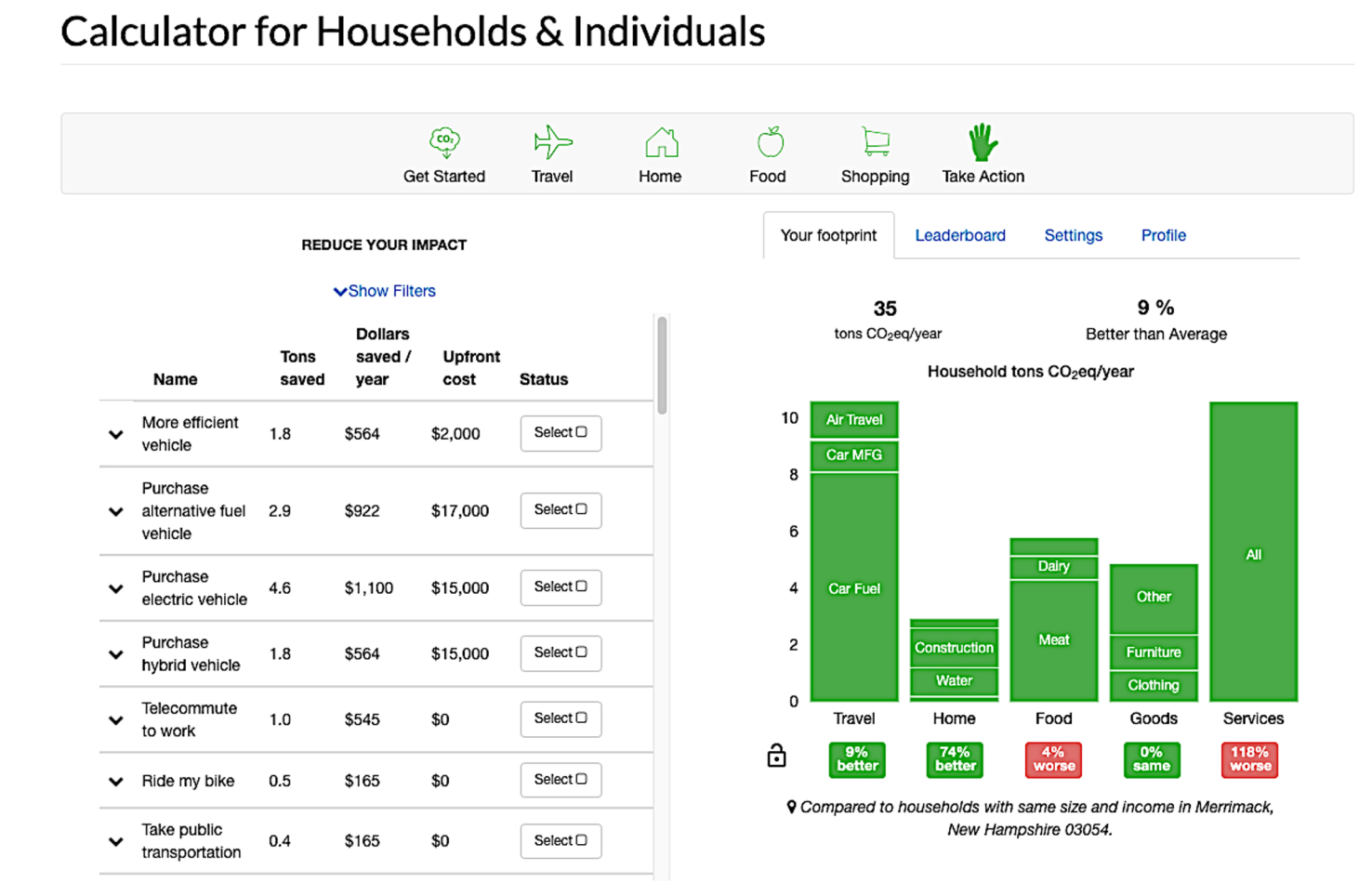
Input data on energy use, transportation, waste, and shopping.

Review results and recommendations for reducing your footprint.

https://coolcalifornia.arb.ca.gov/calculator-households-individuals

UMASS LOWELL
Learning with Purpose

Engage with Your Carbon Footprint



https://coolcalifornia.arb.ca.gov/calculator-households-individuals

Just like calculating your footprint, LCA evaluates the environmental impacts of a product from cradle to grave, considering all stages of its life cycle

Carbon Footprint Calculation:

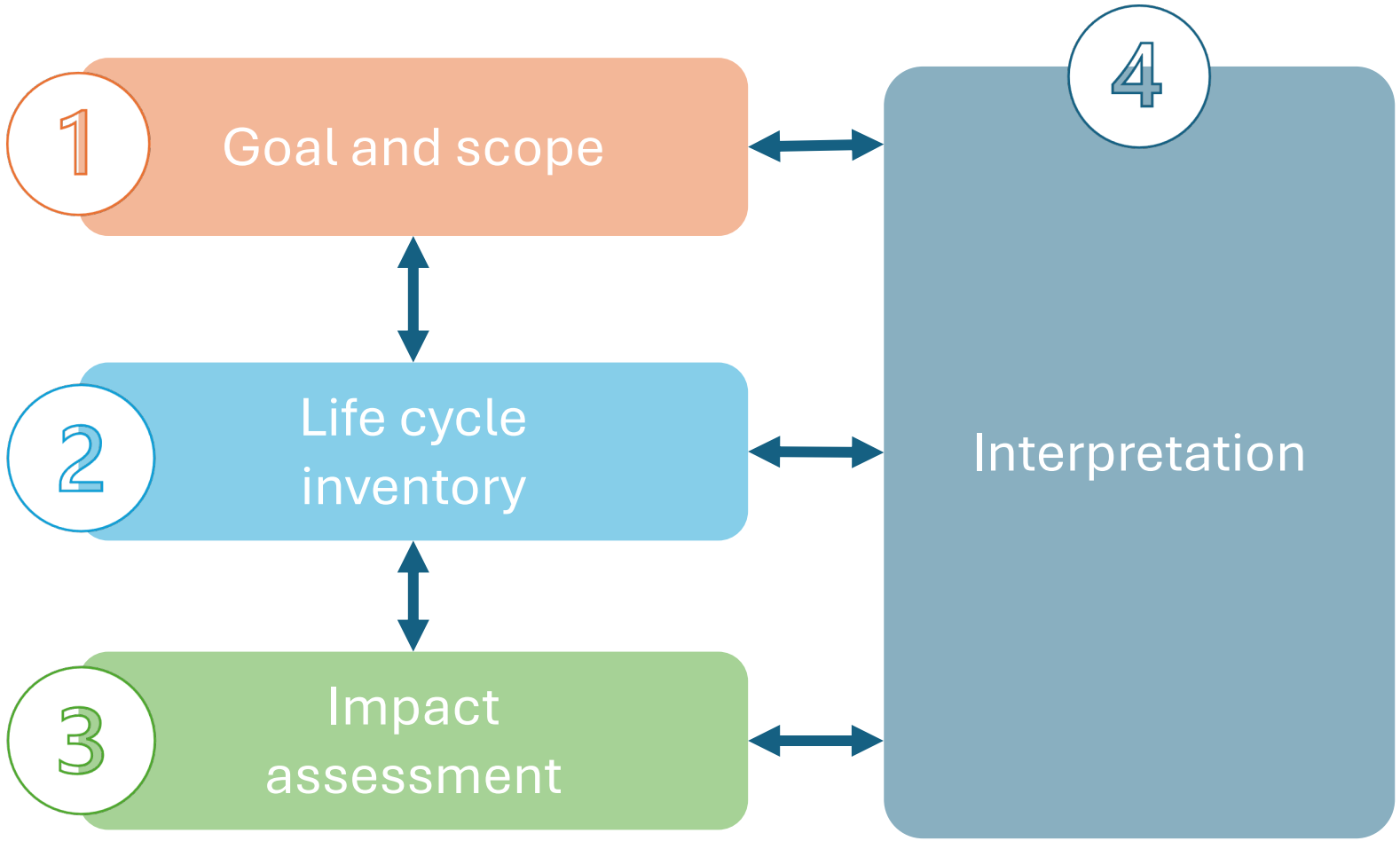
Personal application of LCA principles.

LCA:

Broadly applicable to products, services, and policies, driving sustainable innovation and decision-making

UMASS LOWELL
Learning with Purpose

LCA Phases

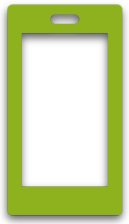


ISO 14040
ISO 14044

1 Goal and scope

Why?

Reason to carry on the study



What for?

Intended application

To whom?

Intended audience

1 Goal and scope

Functional unit

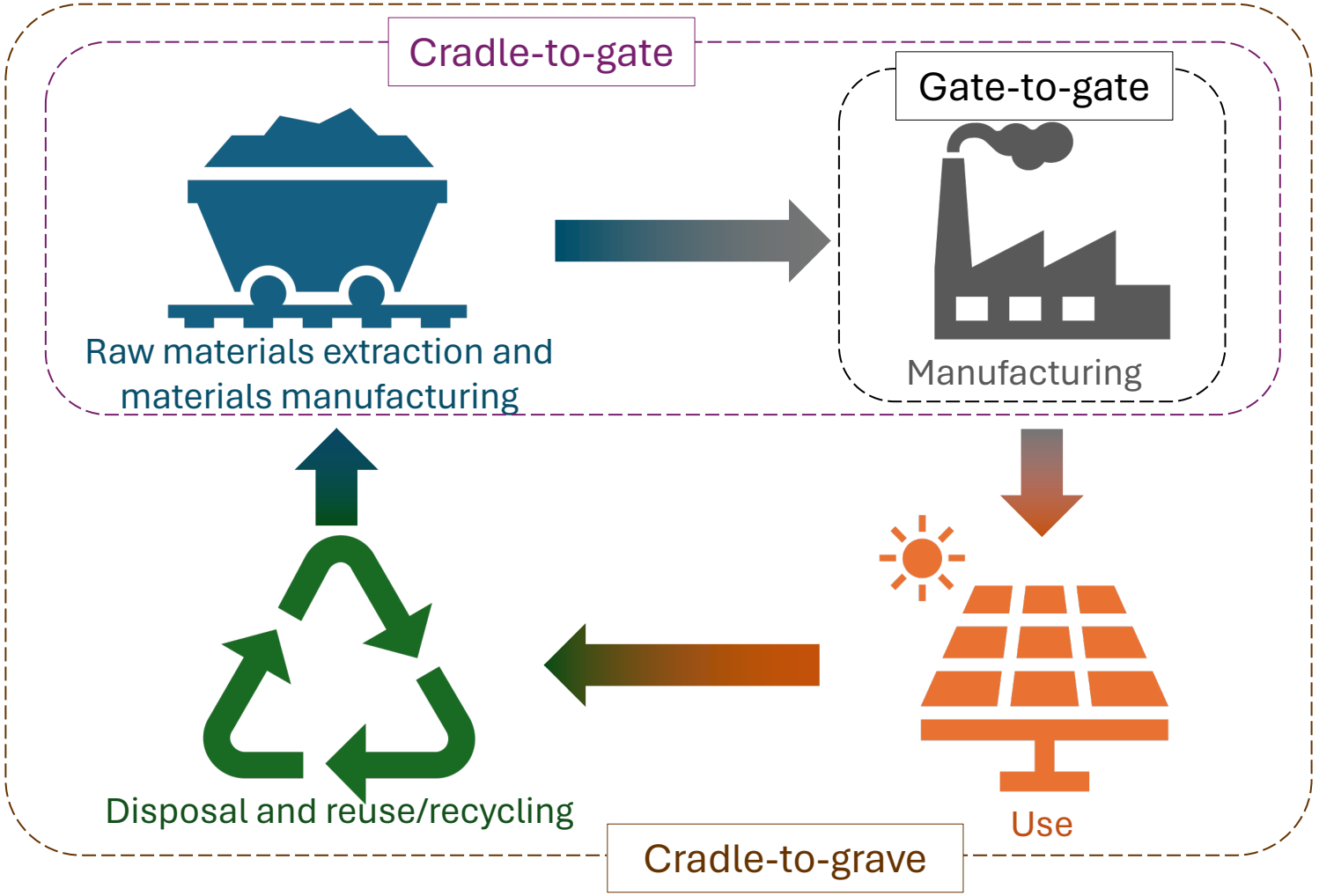
FU:
one hundred pair of dried hands

Reference flows:
xx kWh of electricity
xx pieces of equipment
and packaging

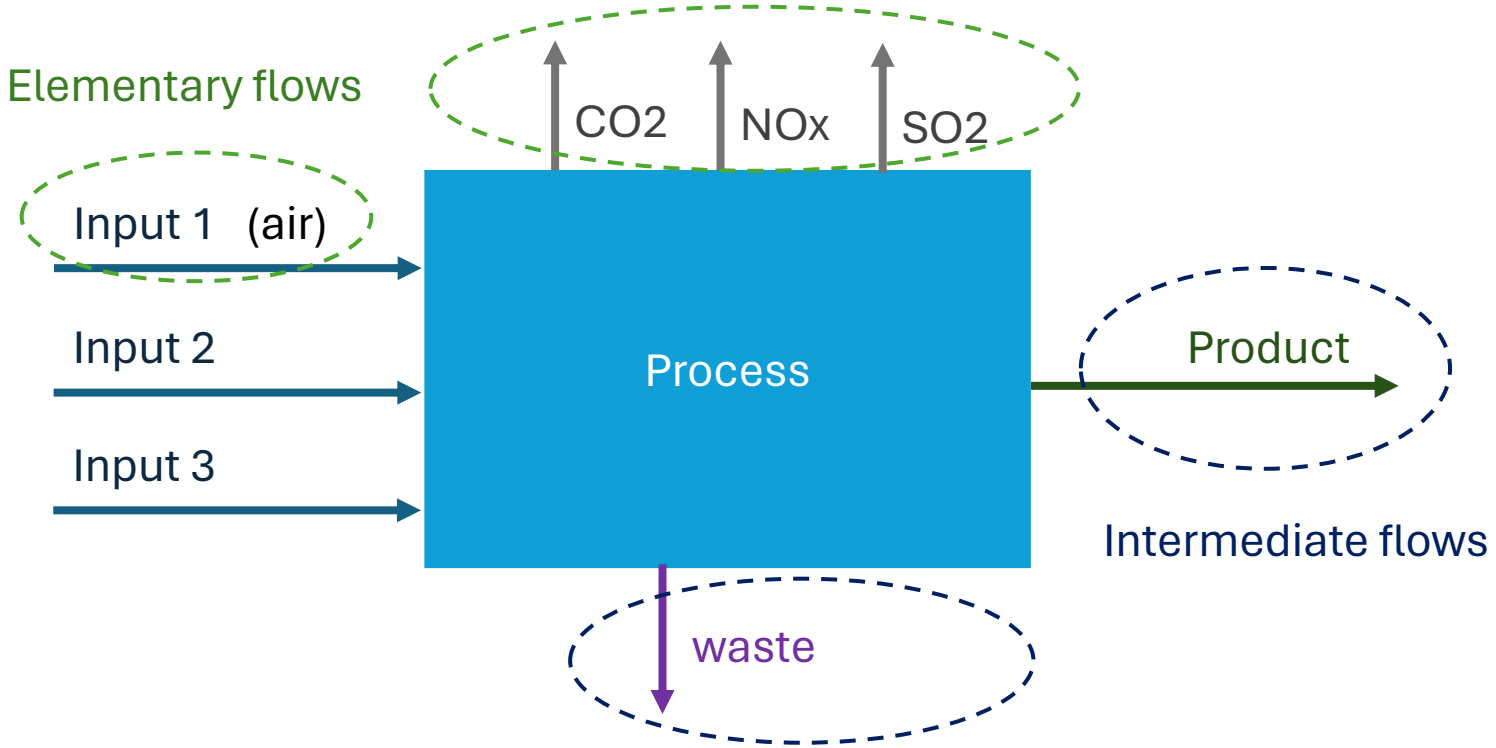
Reference flows:
xx paper towels
xx packaging

1 Goal and scope

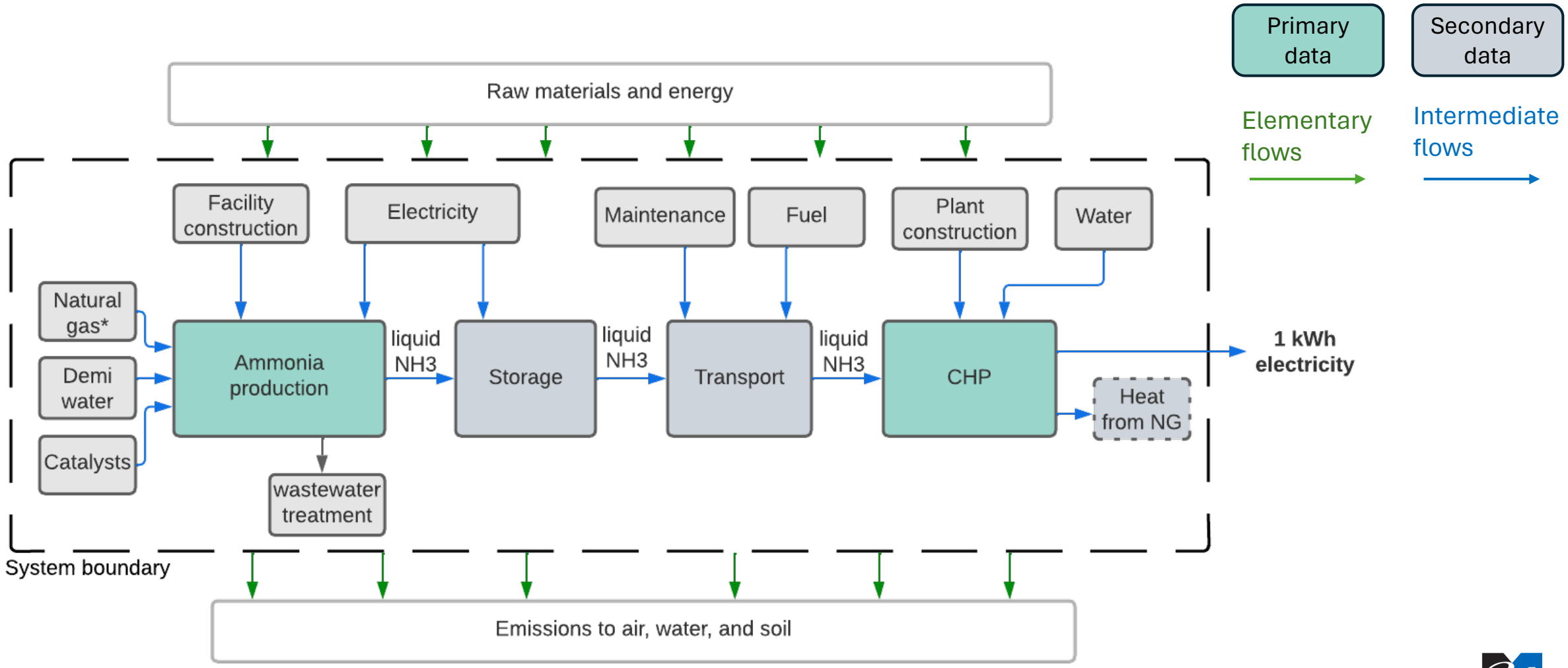
System boundaries



2 Life cycle inventory



2 Life cycle inventory

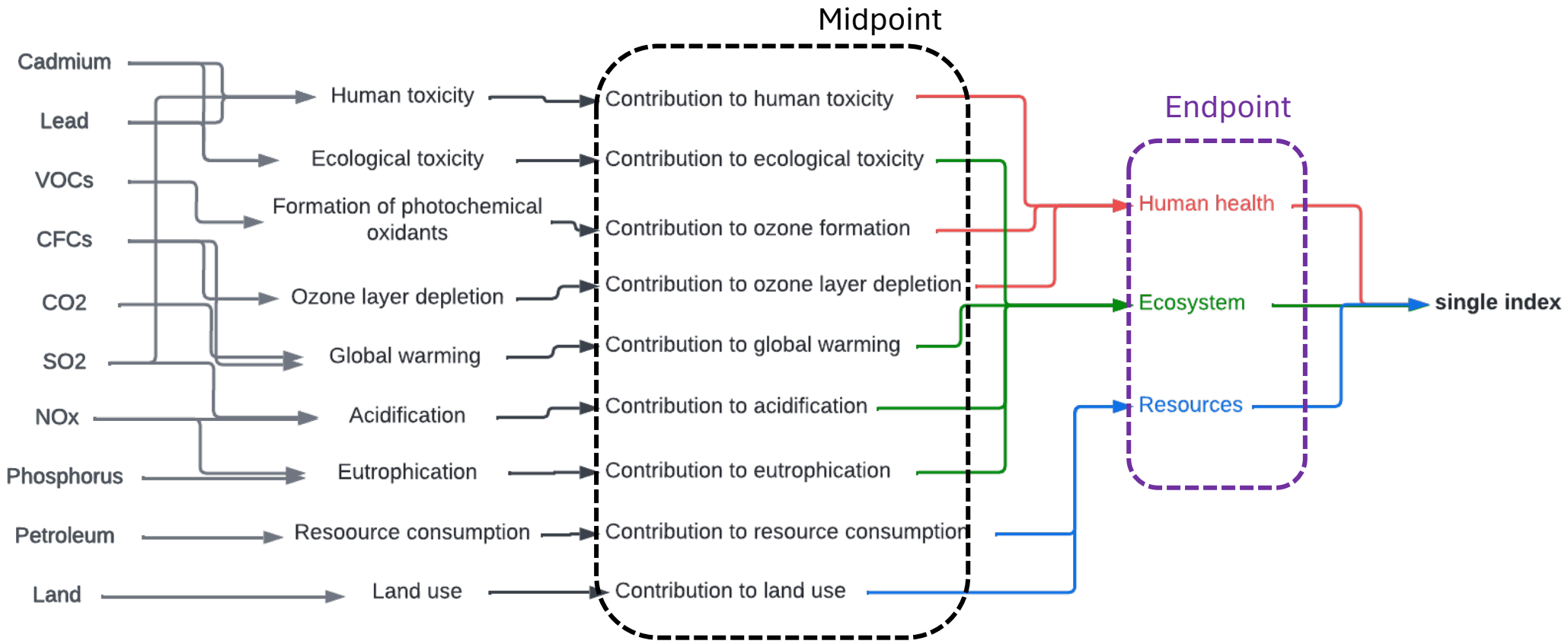


https://doi.org/10.3390/en14206721

3 Impact assessment

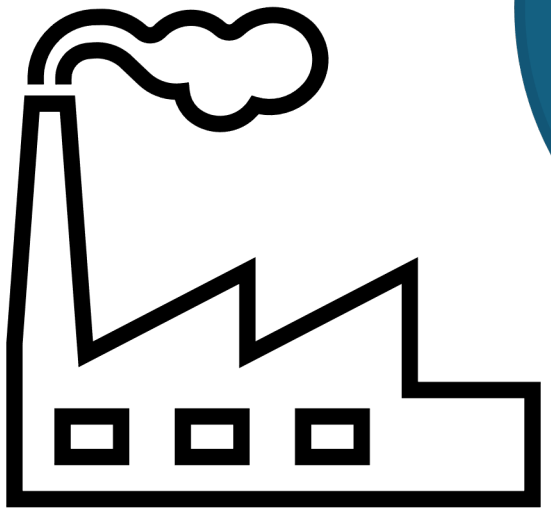
Setting impact categories | Classification | Characterization | Normalization | Grouping | Integration

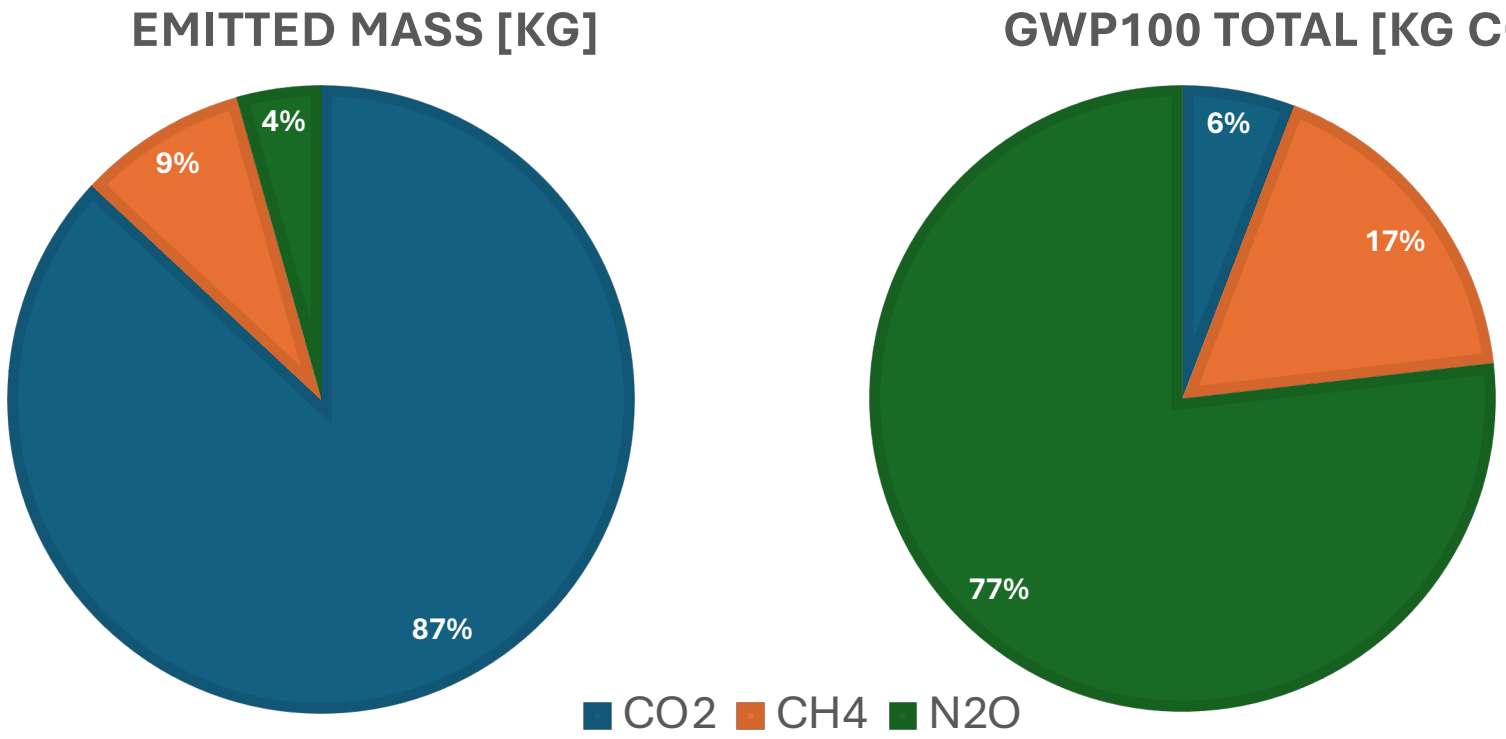
Inventory | Impact category



3 Impact assessment

Characterization





4 Interpretation

Numerical approaches

- Comparative analysis
- Contribution analysis
- Scenario analysis
- Sensitivity analysis
- Uncertainty analysis

Additional elements

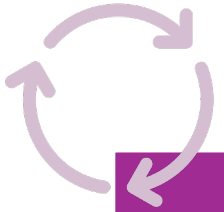
- Identification of relevant findings
- Data quality assessment
- Assumptions and limitations
- Conclusions and recommendations

Future trends

Machine learning in LCA

- Data acquisition and preparation
- Modeling
- Optimization scenarios in LCA

Source: Ghoroghi *et al.* Advances in application of machine learning to life cycle assessment: a literature review. *Int J Life Cycle Assess* **27**, 433–456 (2022). https://doi.org/10.1007/s11367-022-02030-3

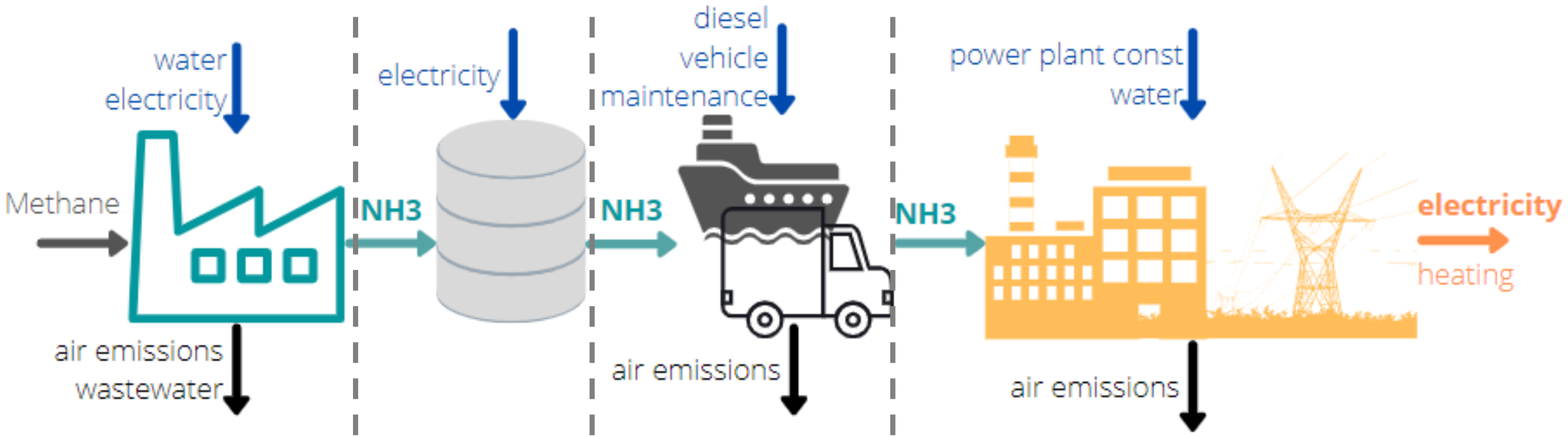


Circular economy

- With LCA we can assess the sustainability of CE.
- Avoidance burden shifting.

Source: Carpenter 2022. The role of Life cycle assessment in a circular economy. https://www.nrel.gov/docs/fy22osti/82677.pdf

Project example: Environmental sustainability of ammonia for power generation



Production
Flows: Proton
Ventures

Storage
Flows: Proton
Ventures

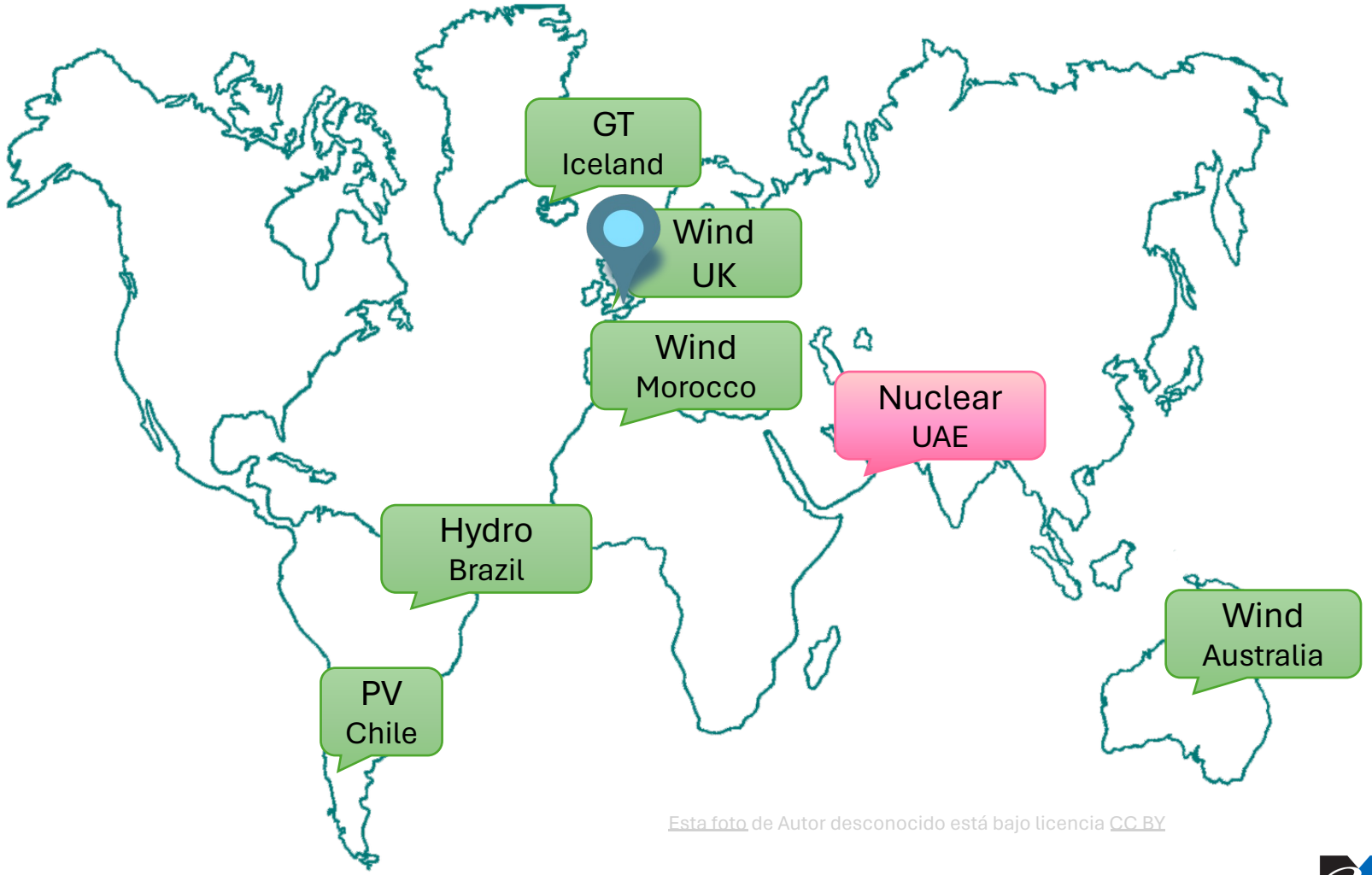
Transport
Average distances
Ecoinvent

Utilization
Flows: Humidified ammonia/hydrogen
RQL combustion in a trigeneration gas turbine cycle

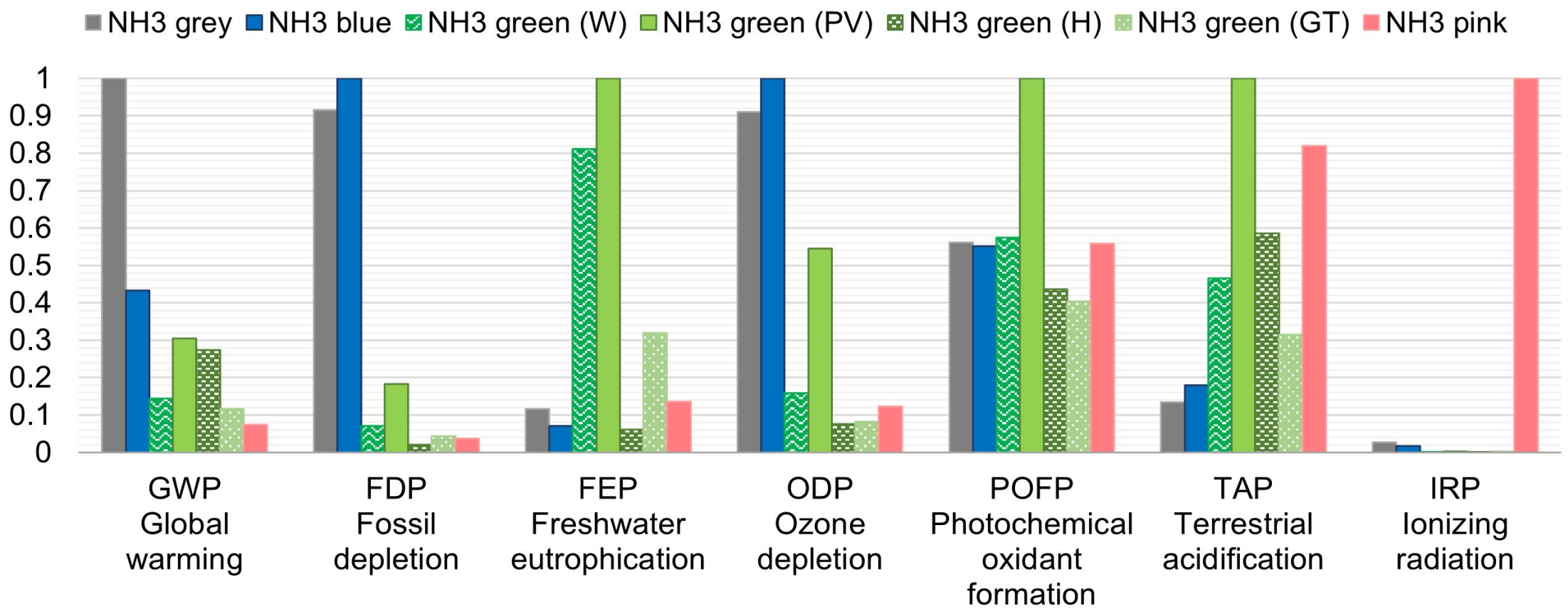
Project example: Environmental sustainability of ammonia for power generation

Goals:

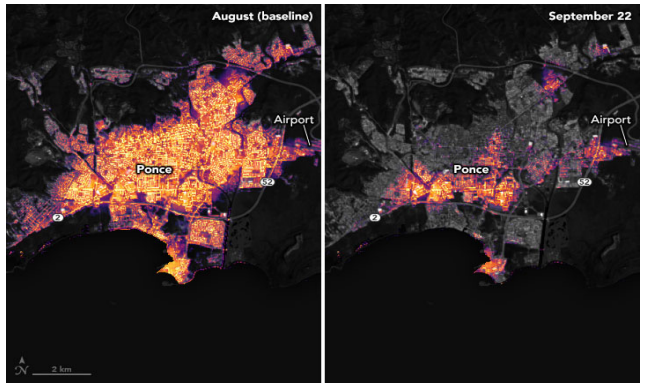
- Compare the environmental performance of ammonia production using different energy resources and different technology scales.
- Compare the environmental performance of ammonia-based electricity generated in the studied CHP system using the different ammonia production pathways.



Project example: Environmental sustainability of ammonia for power generation

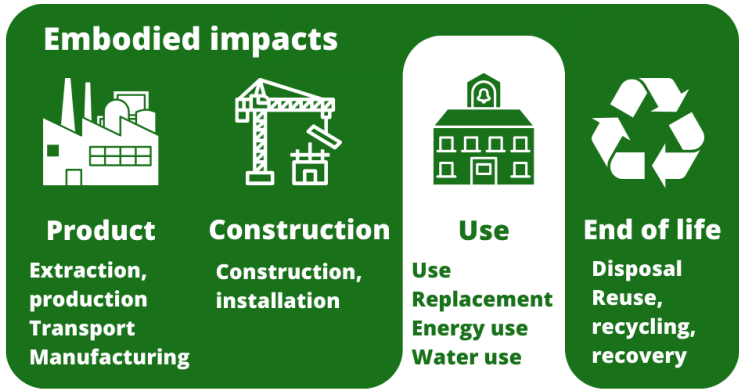


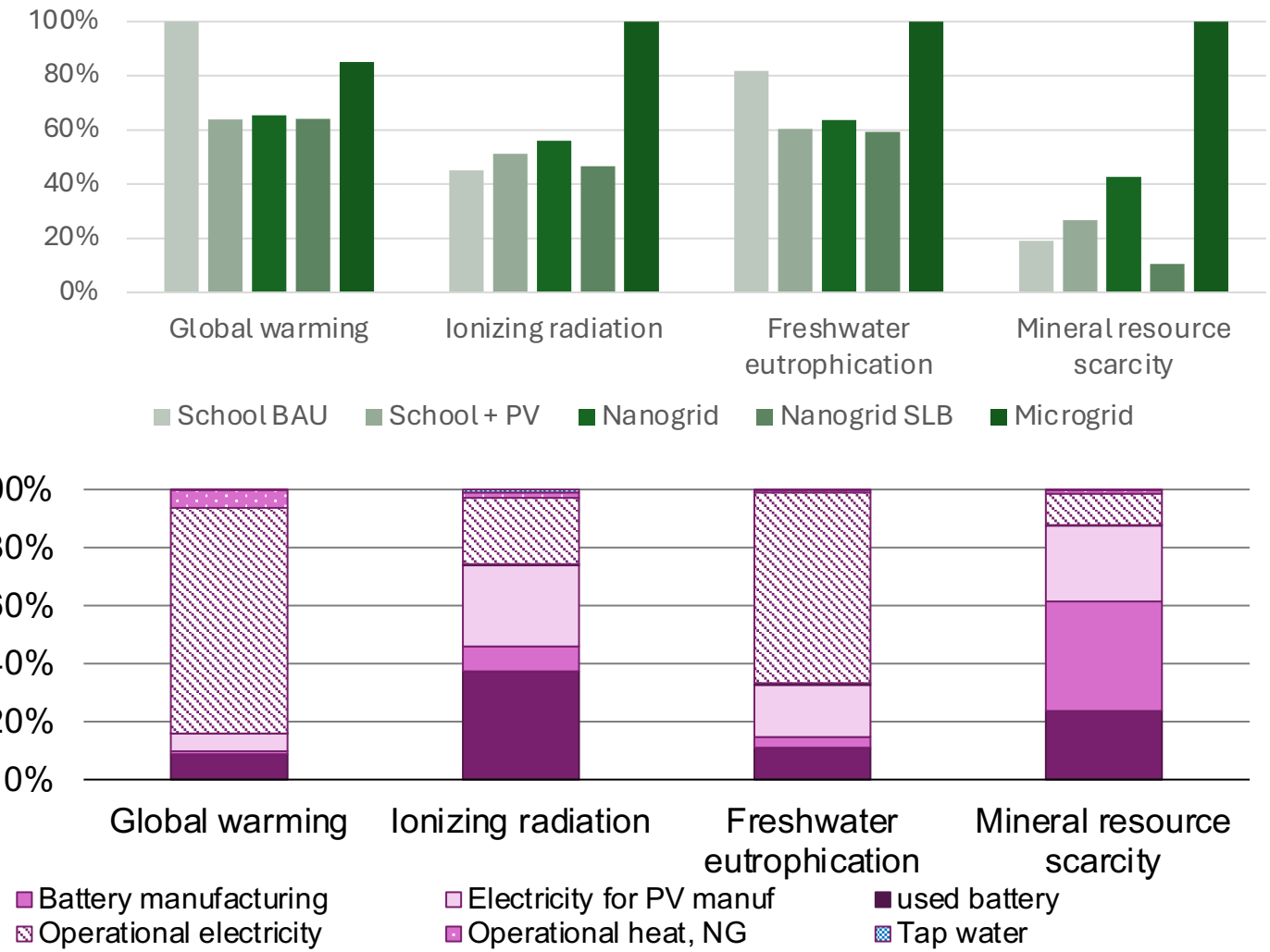
Project example: Energy resilience in schools



GOAL: to assess the benefits of BAPV on school buildings for community energy resilience, the associated environmental impacts, and the costs of transformation.

FU: 1 m^2 of the total floor area of the school building along the lifetime of PV panels (25 years).





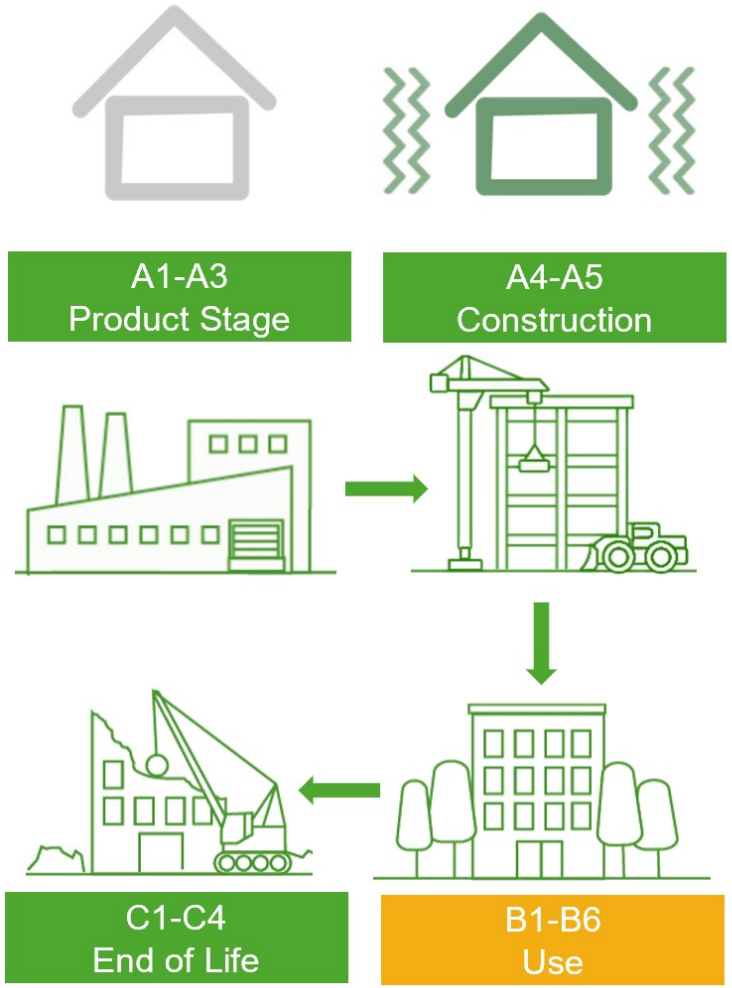
Contribution analysis for nano-grid scenario

UMASS LOWELL
Learning with Purpose

Project example: Parametric Life Cycle Assessment for Resilient Building Design in Miami

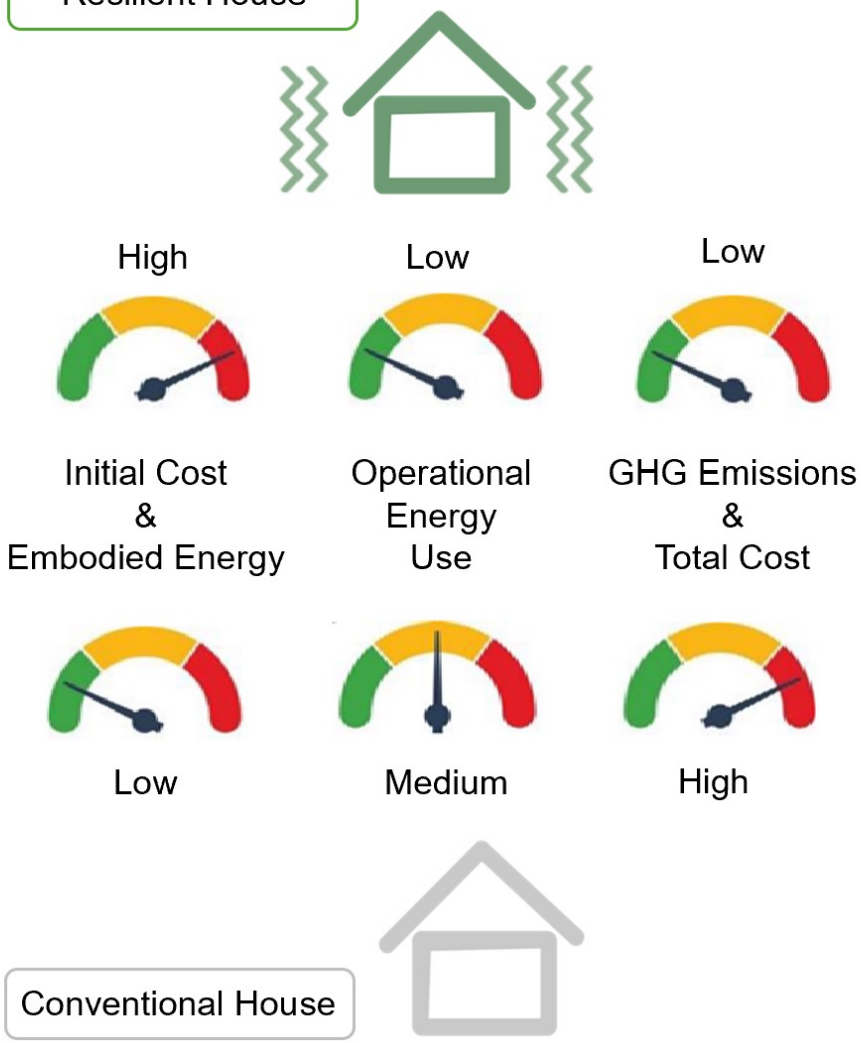
Life Cycle Assessment of Buildings

Conventional House | Resilient House



GHG Emissions, Energy and Cost

Resilient House



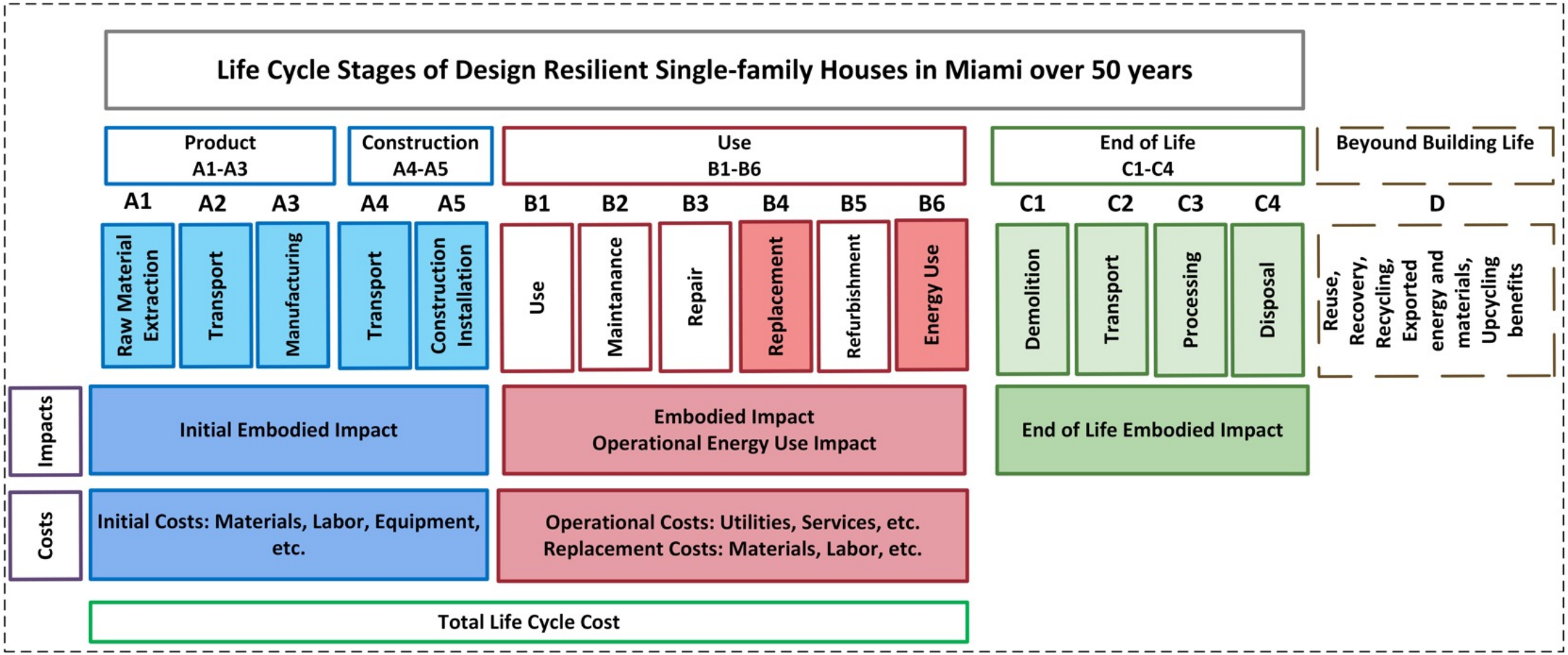
Conventional House

Priority Resilience Goals for Early Design

- Exterior wall finishes
- Window types
- Exterior wall core
- Air conditioning efficiency
- LED lighting ratio window-to-wall ratio

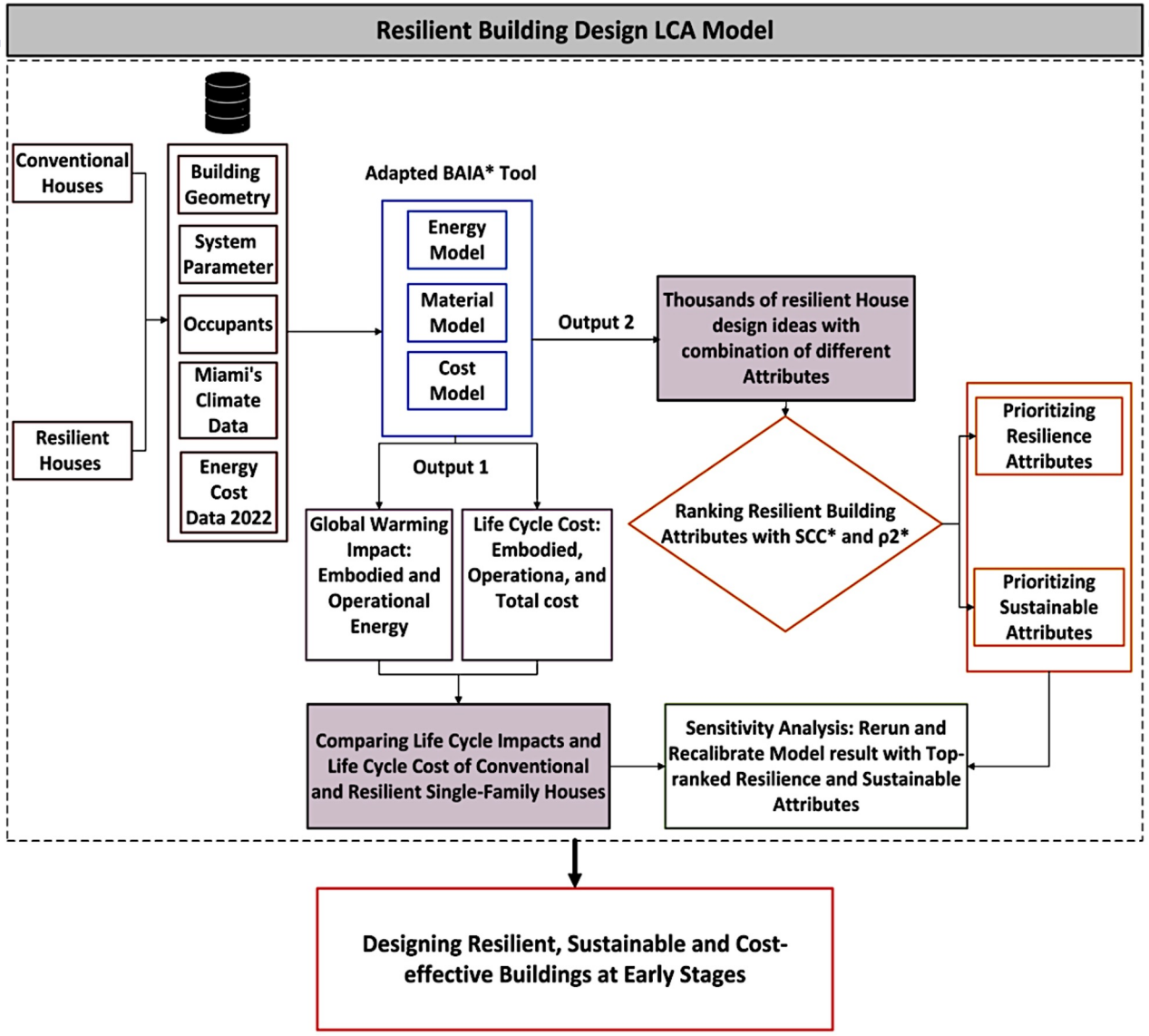
UMASS LOWELL
Learning with Purpose

System Boundary



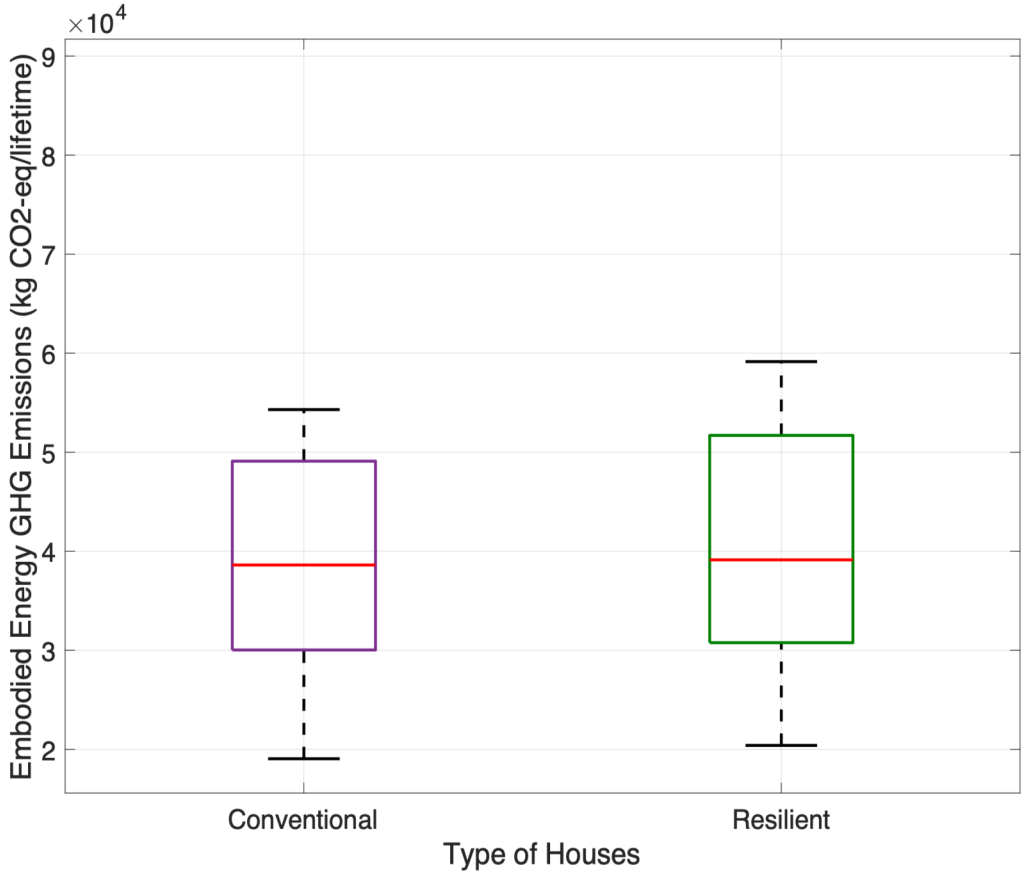
Building life cycle stages, modules, impacts, and costs adapted from [26].

Whole Building Life Cycle Assessment Model

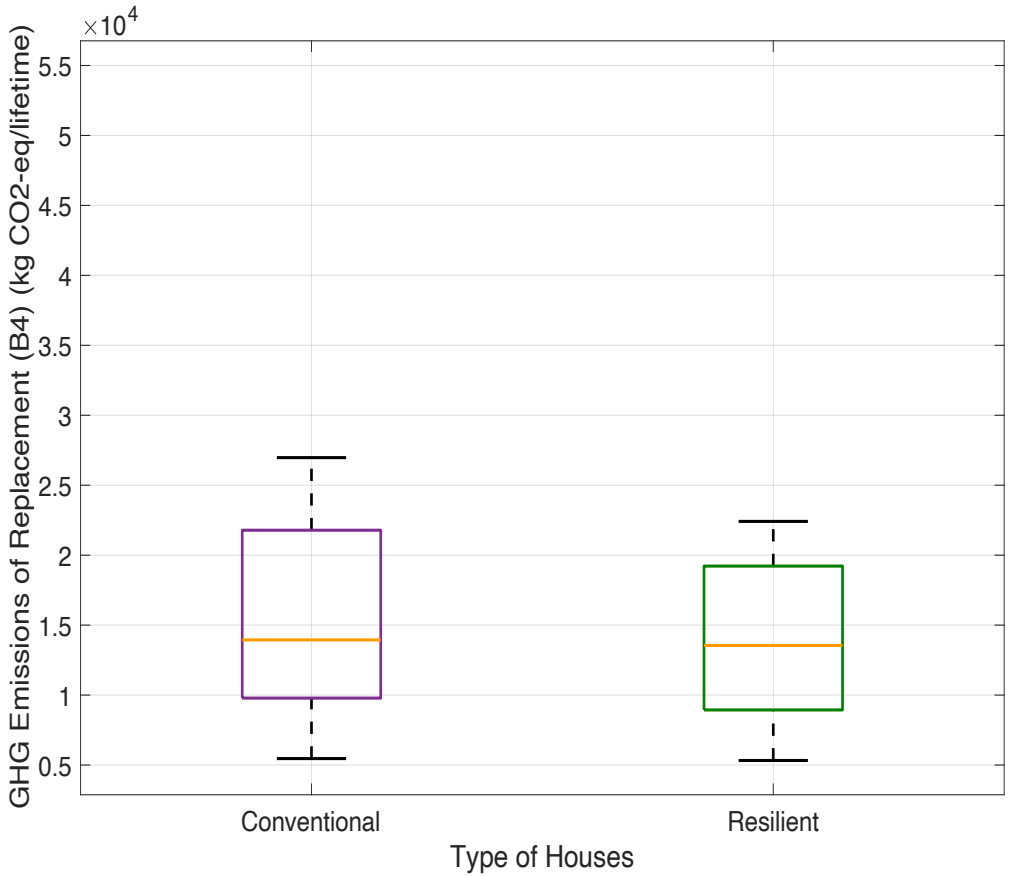


Integrated framework for enhancing resilience in building design: a life cycle assessment model for resilient, environmentally sustainable, and cost-effective single-family houses

Life Cycle Impact Assessment

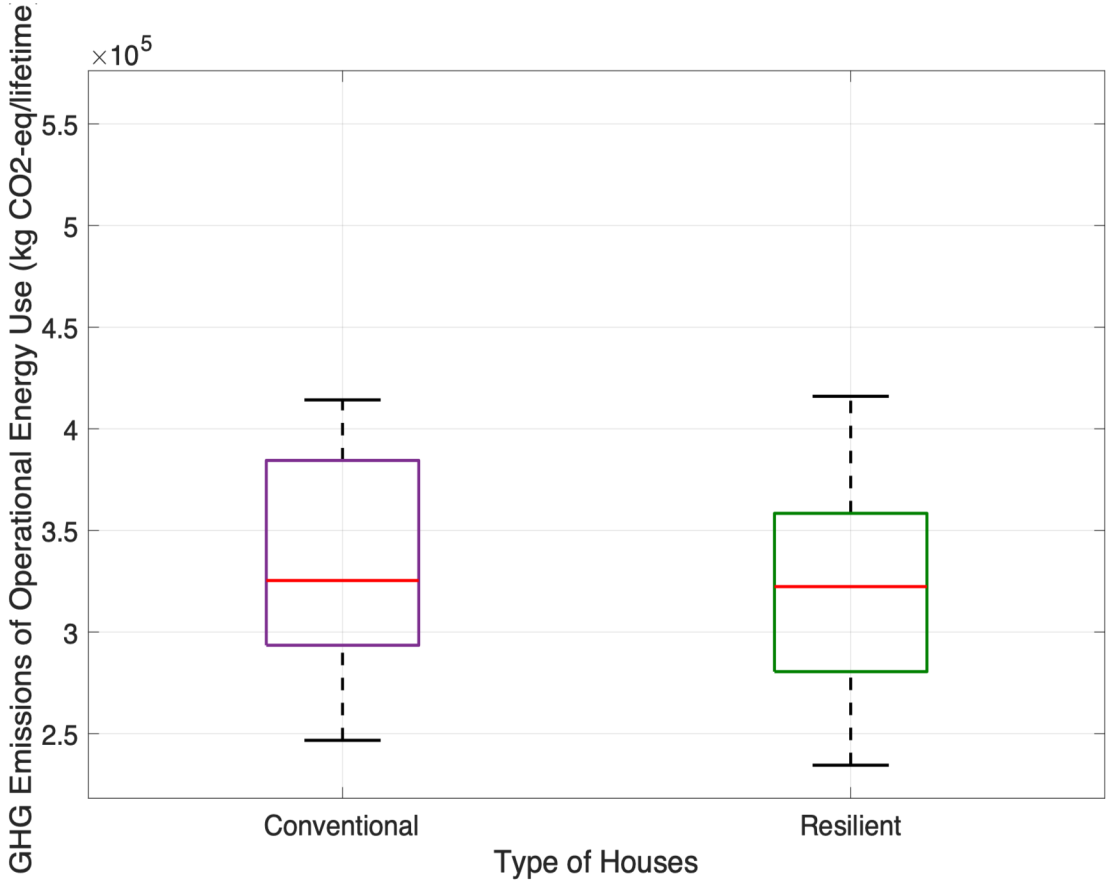


Comparative embodied energy GHG emissions (kg CO2-eq/lifetime)

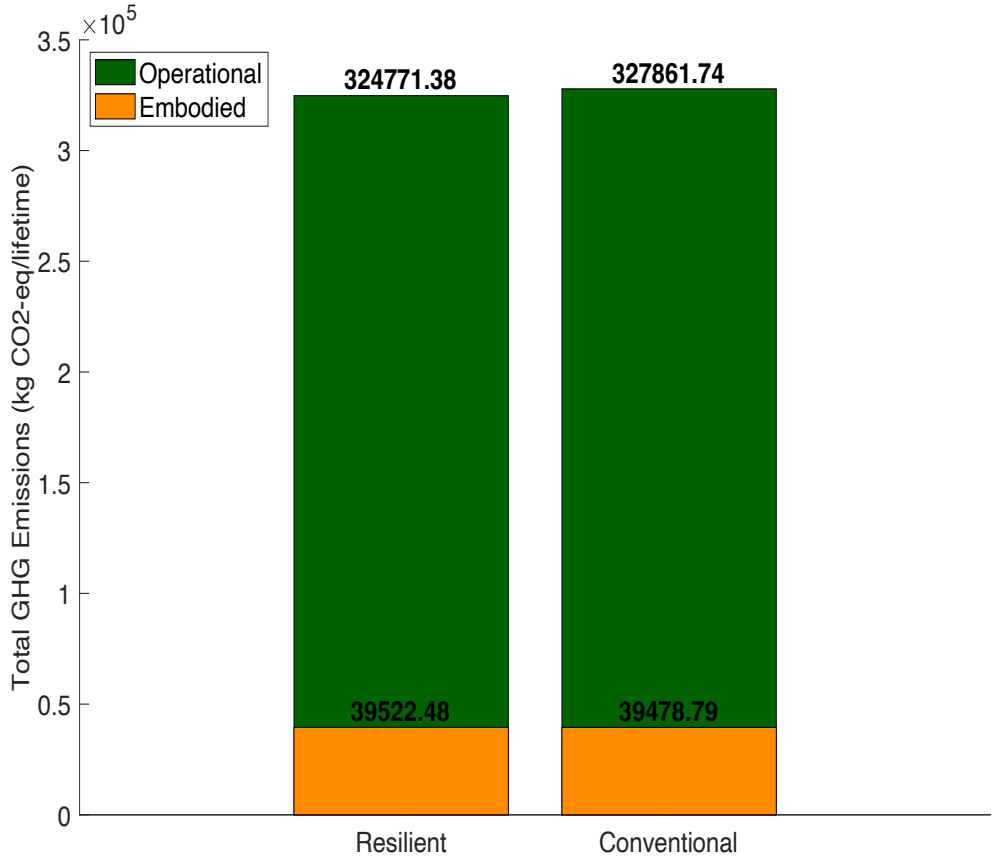


Comparative replacement stage GHG emissions (kg CO2-eq/lifetime)

Life Cycle Impact Assessment



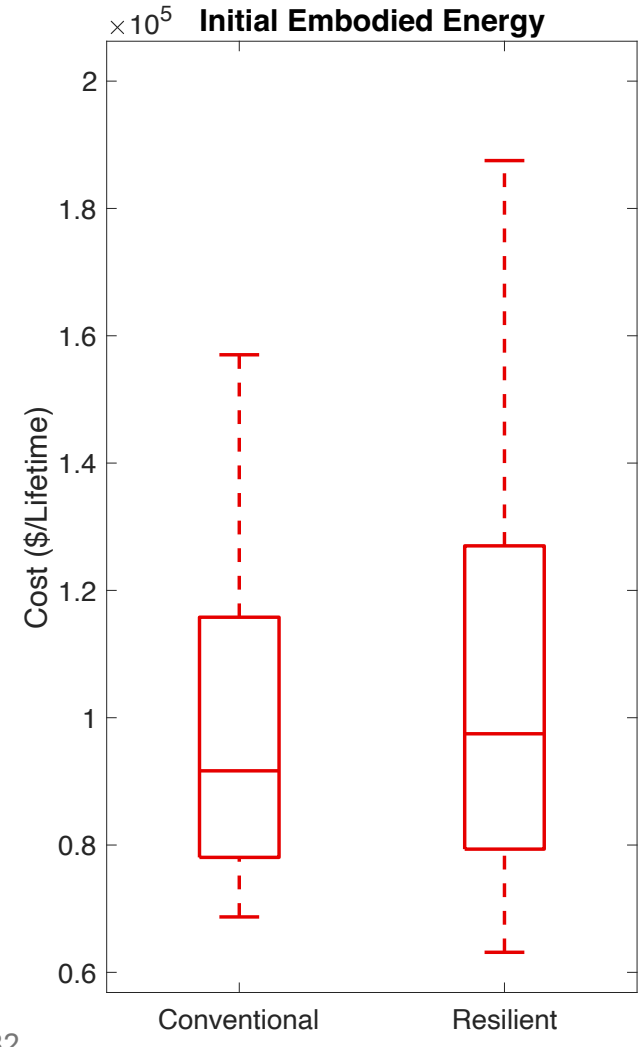
Comparative operational energy GHG emissions (kg CO2-eq/lifetime)

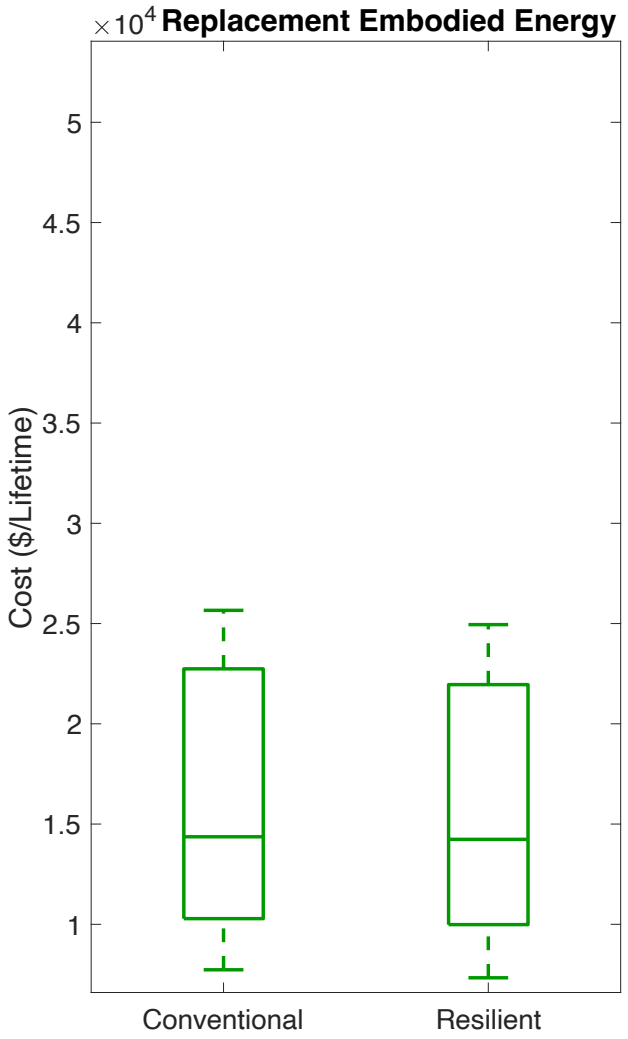


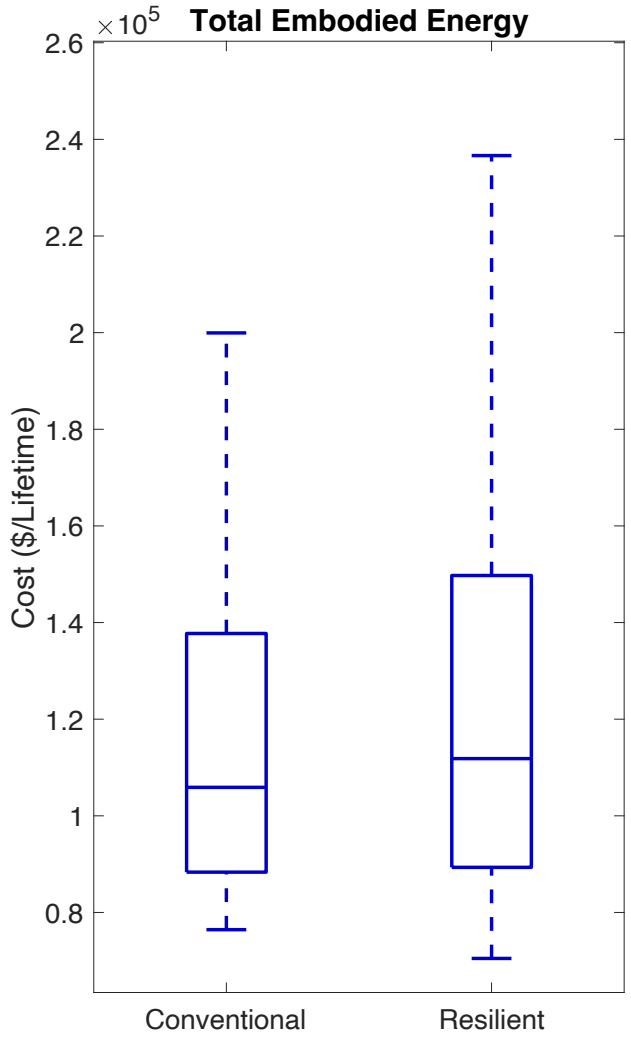
Total GHG emissions (kg CO2-eq/lifetime): embodied vs operational energy

UMASS LOWELL
Learning with Purpose

Life Cycle Cost Assessment

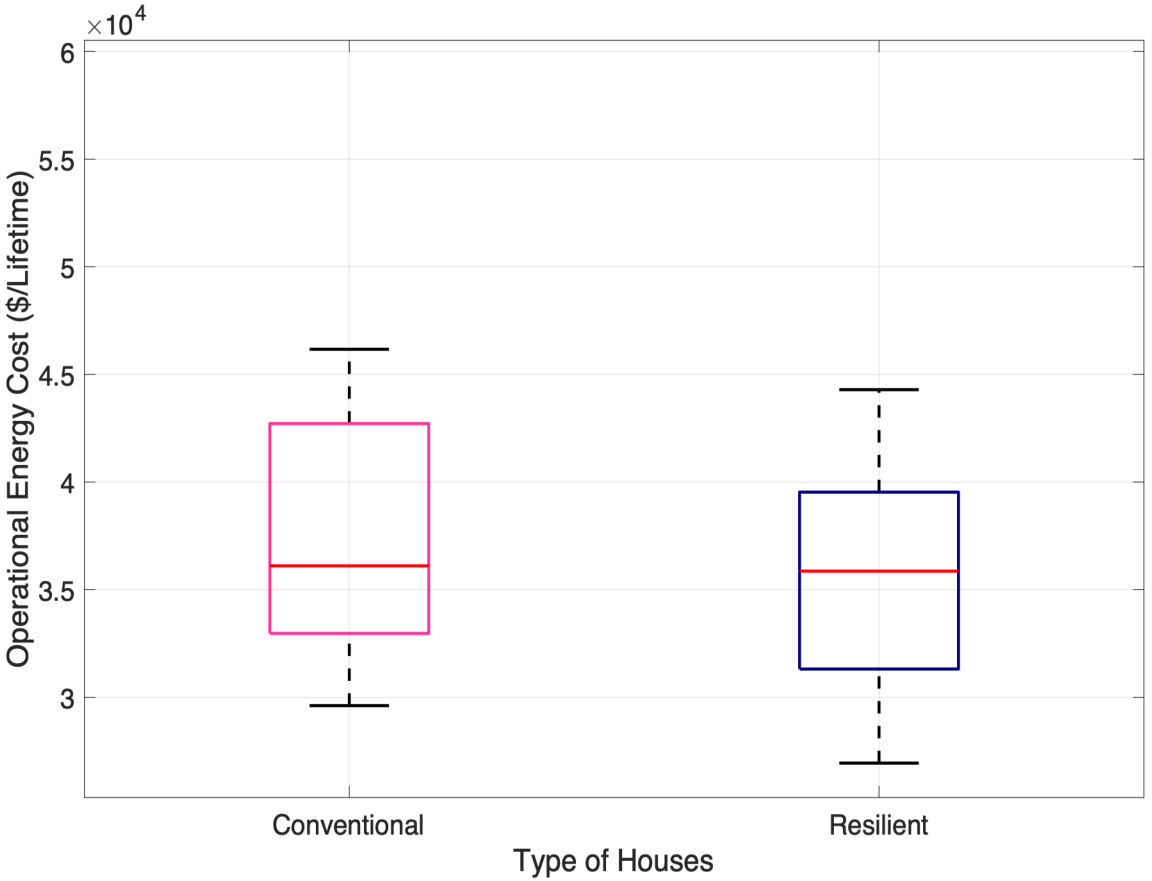


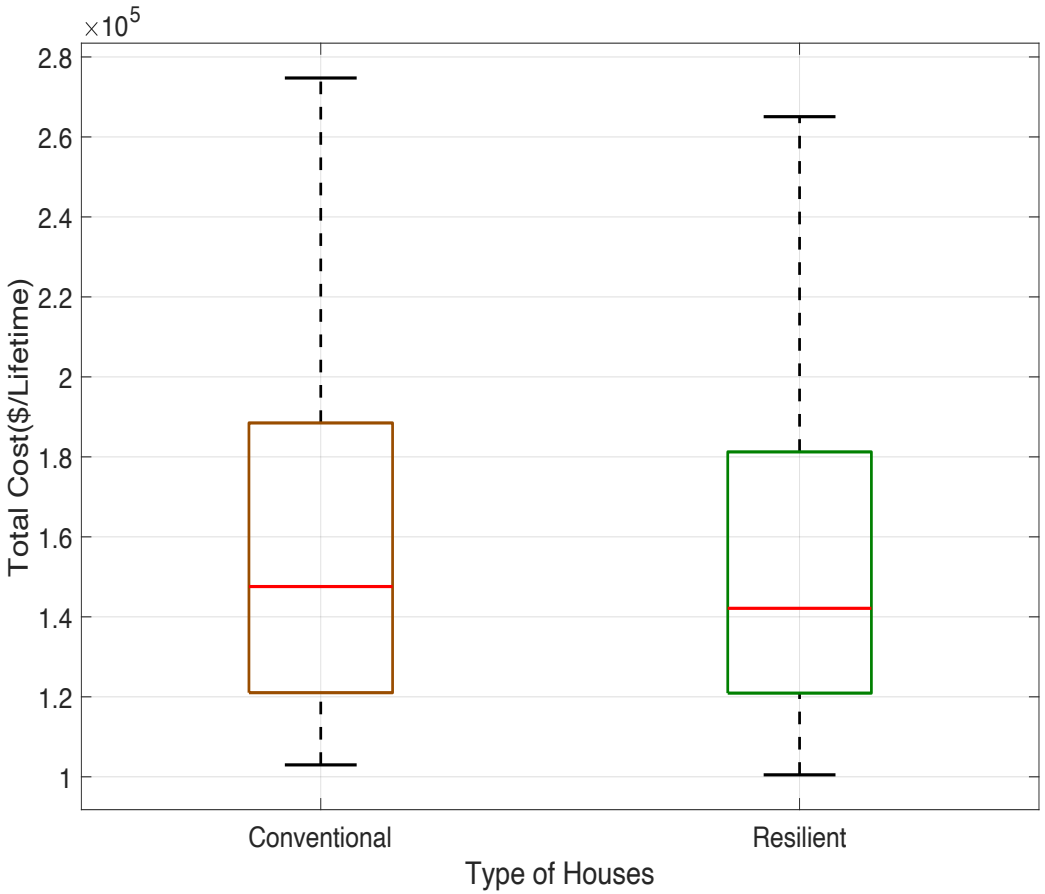




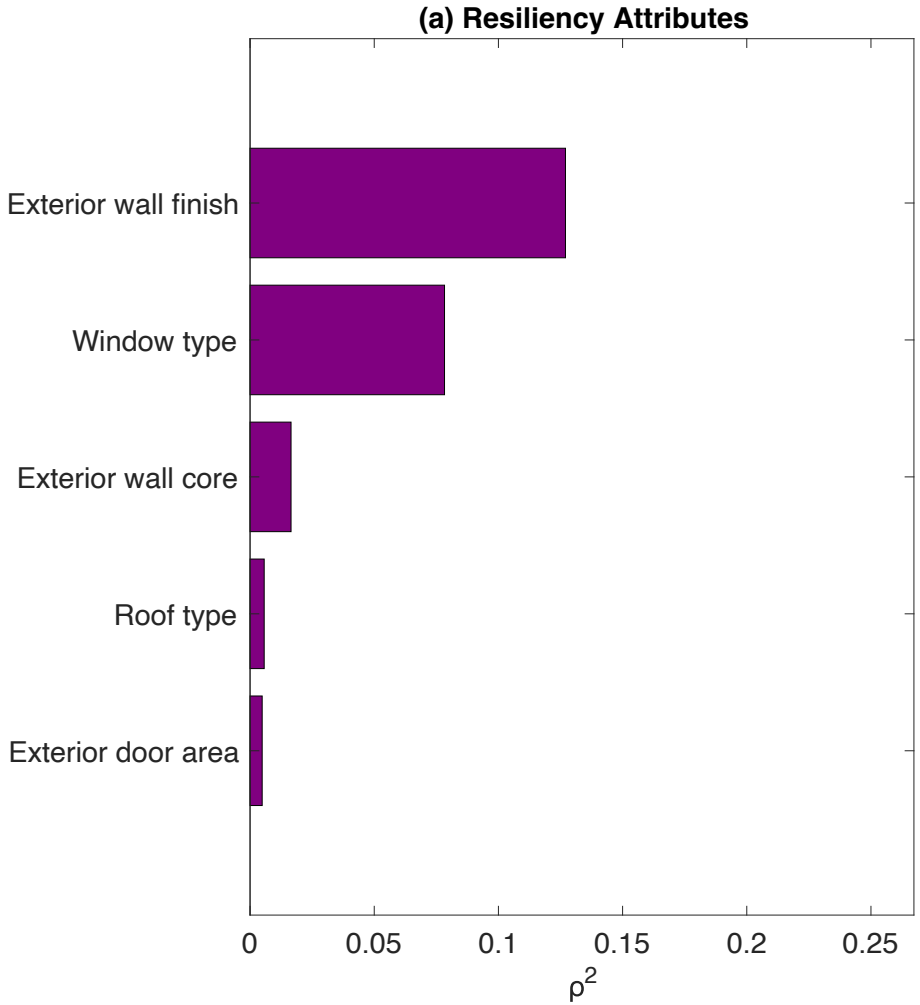
UMASS LOWELL
Learning with Purpose

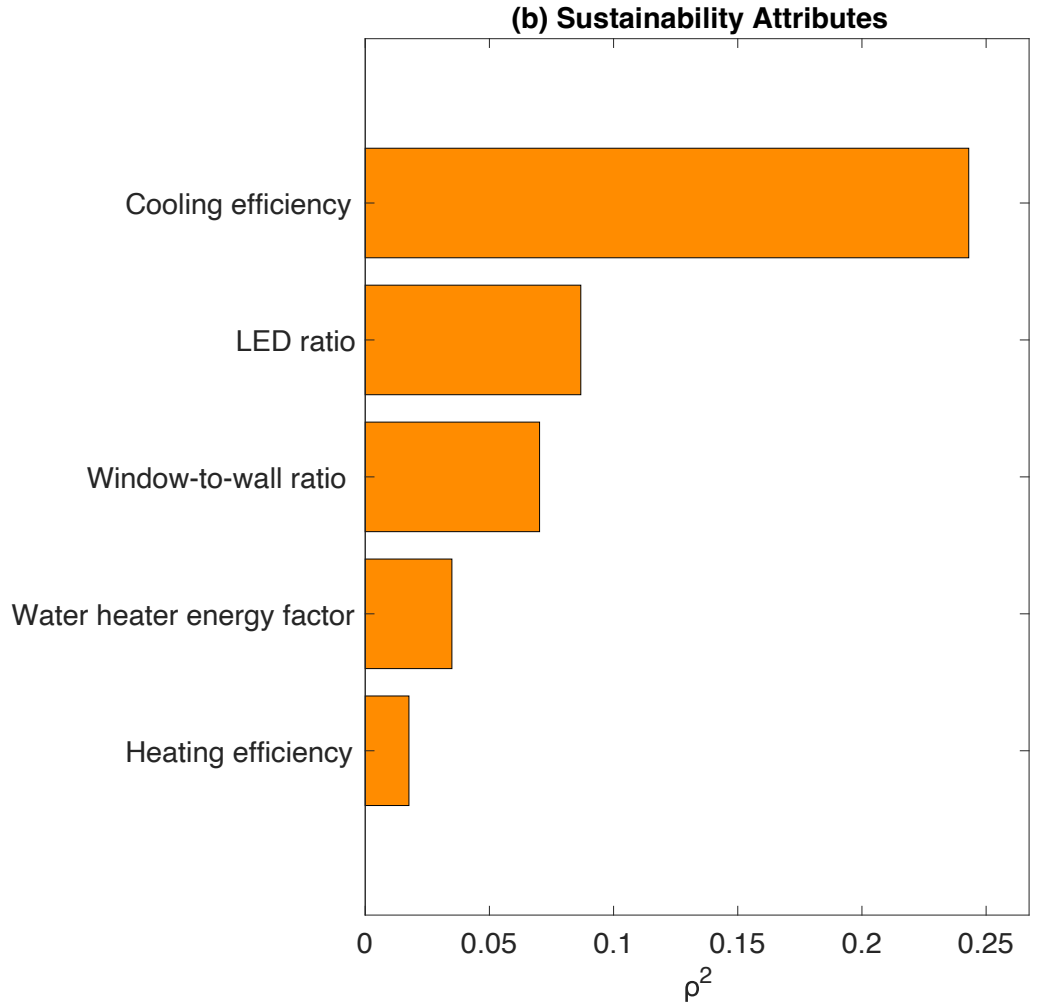
Life Cycle Cost Assessment





Prioritization of Building Design Attributes





UMASS LOWELL
Learning with Purpose

Conclusion

What We Learned:

Resilient Homes: They cost a bit more at first but are cheaper to maintain and run.

Benefits: These homes reduce energy costs and emissions and are better for the planet.

Next Steps:

Research more types of buildings and areas to keep improving our homes for the climate challenges ahead.

Key Takeaway

Importance:

LCA supports the design of buildings that are not only more durable and cost-effective but also environmentally friendly.

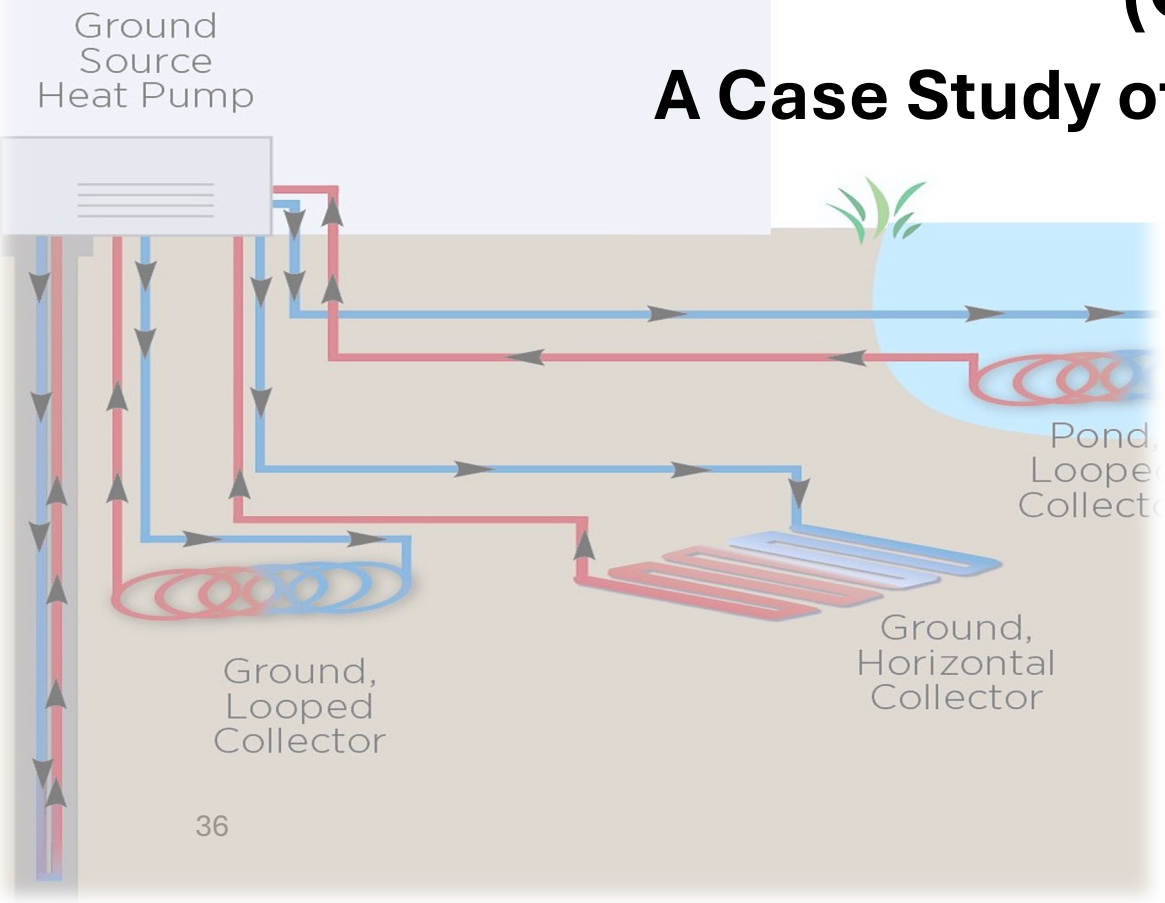
LCA Application:

Helps in making informed decisions by quantifying cost, energy, and environmental benefits over a building's life cycle.

Project example: Geothermal VS HVAC systems

Enhancing Decarbonization through Life Cycle Assessment of Networked Geothermal Systems (GeoNets)

A Case Study of Lowell, Massachusetts



Learning with Purpose

Lowell Networked Geothermal Design

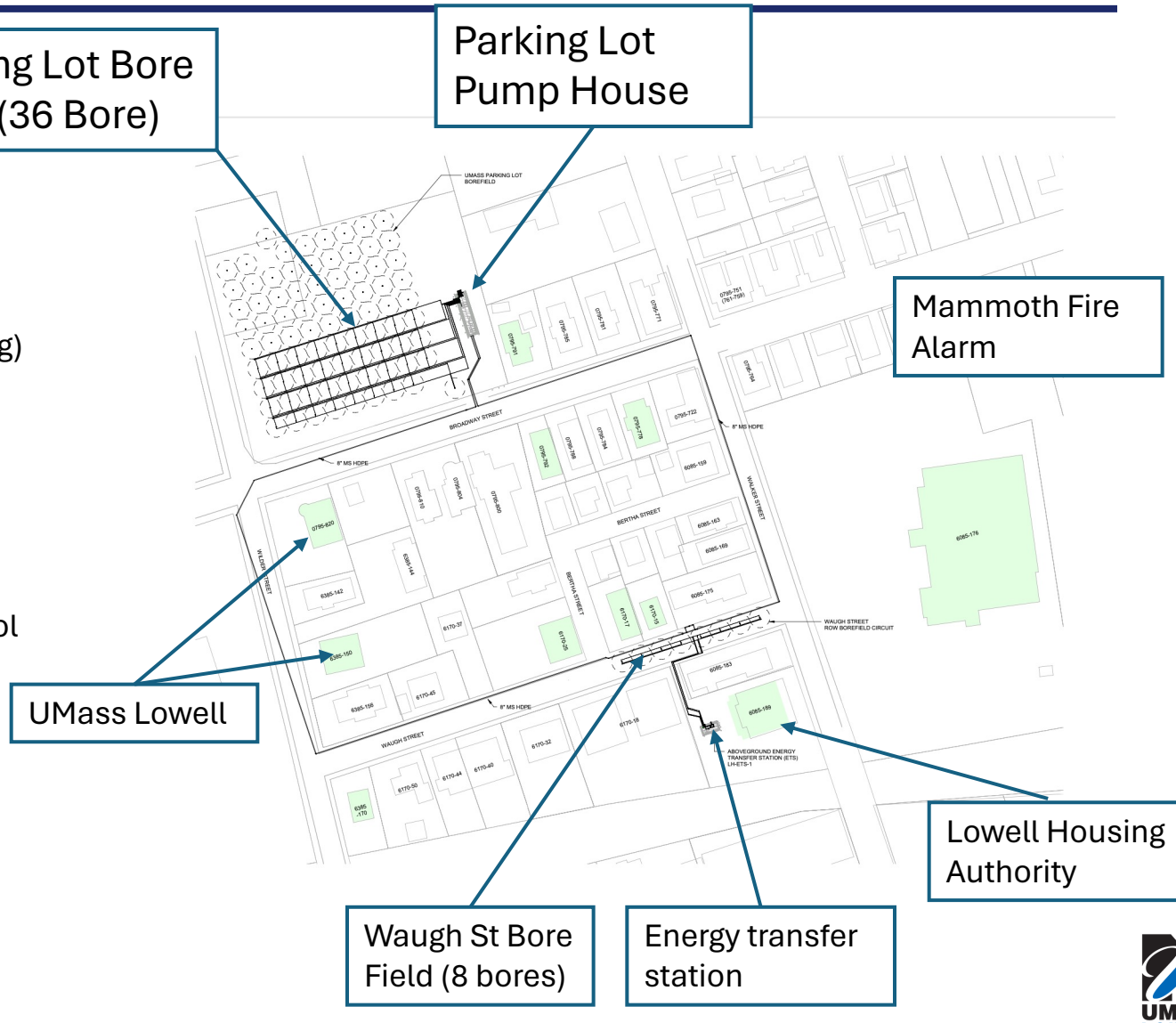
Lowell Networked Geothermal Design

System Overview:

- **Total Customers:** Approx. 27-32
- **Total Buildings:** 11
  - **Commercial:** 3 (including UMass Lowell and Mammoth Alarm)
  - **Residential:** 8 (including Lowell Housing Authority building)

Design Characteristics:

- **Bore Fields:**
  - Parking Lot Bore Field: 36 bores
  - Waugh St Bore Field: 8 bores
- **System Capacity:** Delivers 143 Tons of thermal capacity
- **Bore Depth:** 600 ft with 25 ft spacing
- **System Volume:** ~13,204 gallons of water and 25% propylene glycol mixture
- **Distribution Loop:** ~2,000 ft of 8" main, supports the entire block
- **Pressure:** Max operating pressure of 70 psi
- **Service Lines:** Range from 2", 3", and 8" for large customers
- **Pumping Stations:** Two (Main Pump House and Energy Transfer Station)



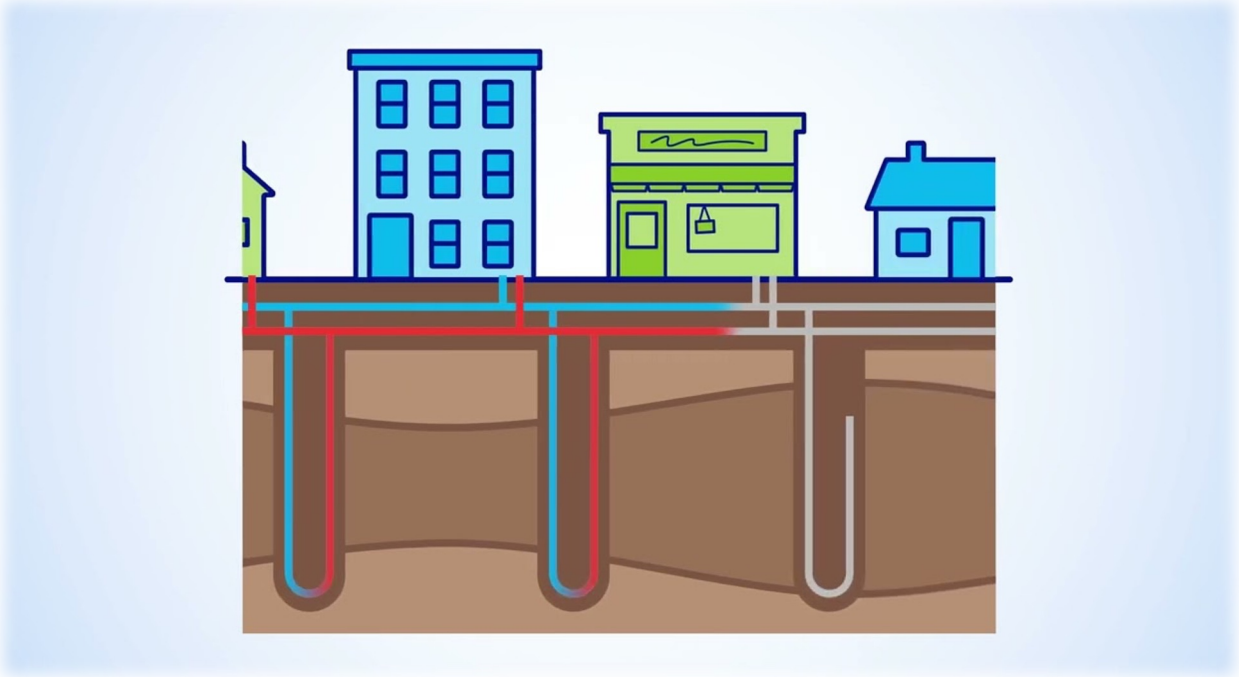
UMASS LOWELL
Learning with Purpose

Goal and Scope

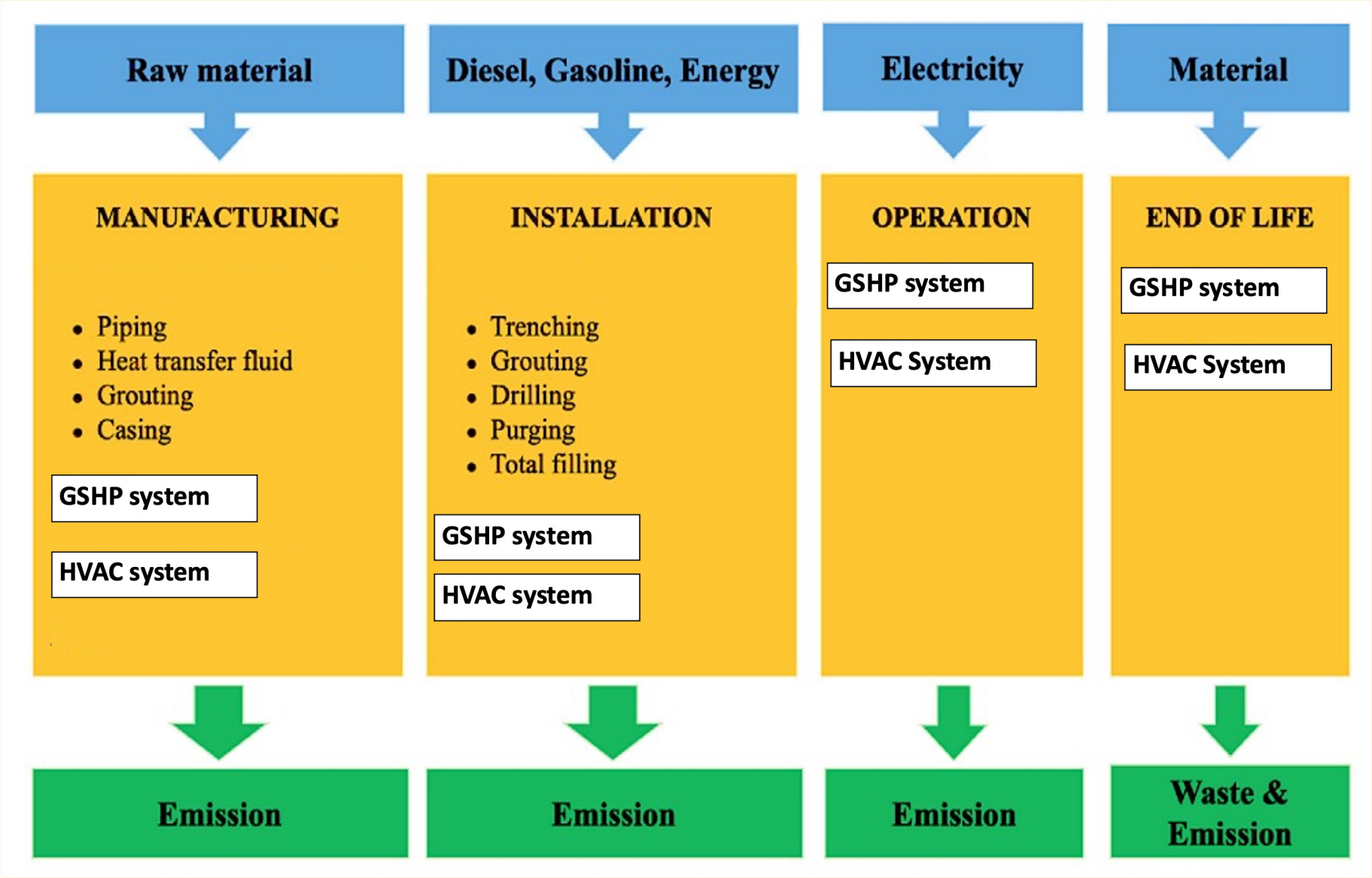
Goal: To analyze and compare the environmental and economic lifecycle of GSHP and conventional HVAC systems.

Scope: the entire lifecycle including manufacturing, installation, operation, and end-of-life disposal.

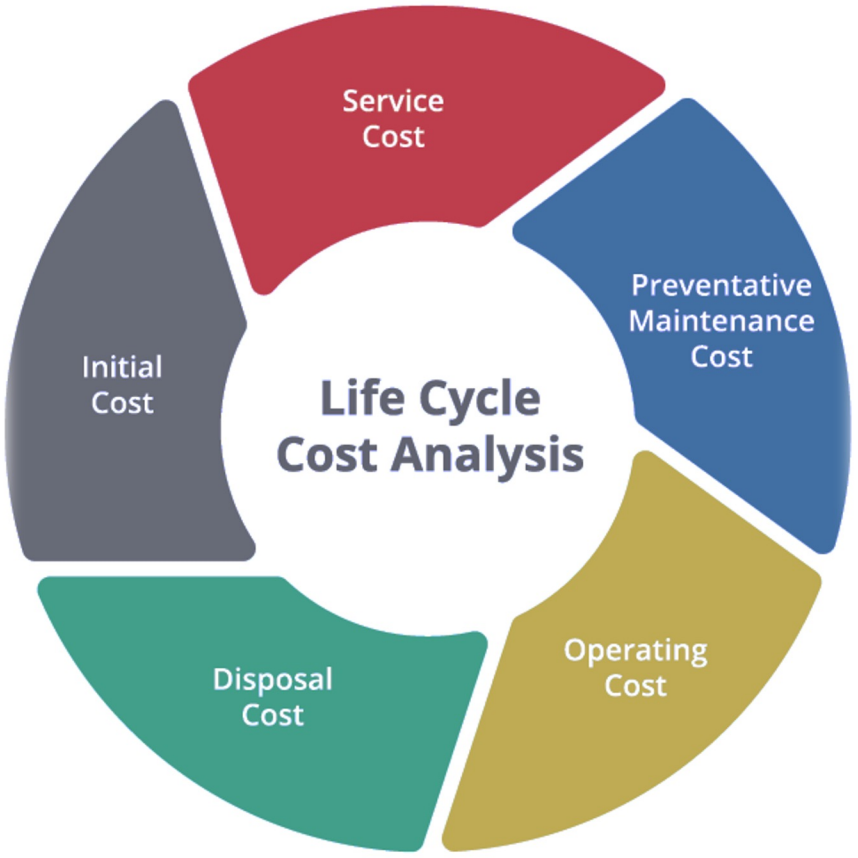
functional unit: Total thermal energy delivered (kWh) by the GSHP and HVAC systems over their expected operational lifetimes.



System Boundary



Life Cycle Impact and Cost Assessment



Global Warming Potential (GWP)	Ozone depletion	Energy Use
Human Toxicity (cancer and non-cancer related)	Air Pollution	Water Pollution
Resource Depletion	Eutrophication	Acidification
	land use	

Expected Outcomes

GSHPs significantly reduce operational GHG emissions and energy use

Lower global warming potential and enhanced energy efficiency

Despite higher initial costs, lower long-term operational cost

Variation of results in different geographical locations

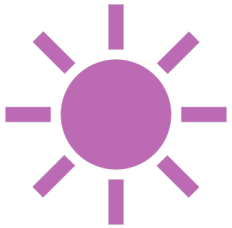
GSHPs are not only environmentally friendly but also economically viable over their lifespan

LCA—A Keystone for Sustainable Energy Futures

Why LCA Matters for Energy

Full Picture: LCA shows the total environmental impact of energy systems, from production to disposal.

Smart Choices: It helps us make informed decisions about using energy in ways that are better for the planet.



LCA's Impact

Boosting Renewable Energy: By evaluating things like solar panels or geothermal systems, LCA ensures these technologies are truly beneficial for the environment.

Guiding Policies: The insights from LCA are crucial for creating policies that promote clean, efficient energy use.

Looking Ahead

LCA will continue to be a key tool in making sure our energy solutions are effective and sustainable, helping us build a future where both people and the planet can thrive.

Comprehensive Tools for LCA

Databases

Ecoinvent: Rich source of global life cycle inventory data.

USLCI: U.S. Life Cycle Inventory database managed by NREL.

GaBi Databases: Provides detailed environmental impact data.

IDEA v2: International Database for Enhanced Assessments.

SimaPro Database: Offers a collection of datasets integrated into SimaPro software.

Software Tools

SimaPro: Popular tool for detailed life cycle analysis.

GaBi: Versatile software for life cycle engineering.

OpenLCA: Free, open-source LCA software supporting various databases.

Brightway2: Flexible and powerful Python framework for LCA.

Umberto: Combines LCA and material flow analysis in one tool.

Online Platforms and Tools

Cap'LCA: Web tool for simplified LCA assessments.

EarthSmart: IBM's tool for quantifying environmental impacts of products.

LCA Calculator: Simple online tool for quick LCA calculations.

Guidance and Standards:

ISO 14040 and 14044: International standards for conducting and reporting LCA.

SETAC: Society of Environmental Toxicology and Chemistry provides guidelines and conferences on LCA.


Thanks For Your Attention
Q&A