Module A3
Life cycle assessment & Return on energy investment

AAE-E3120/AAE-E3121 Circular Economy for Energy Storage

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Šimon Jech

What is a life cycle

Sala et al., 2016

And why on this course

- **Life cycle assessment - tool to asses different energy storage solutions**
- **Can be used for actual ECODESIGN**
    - Comparing options
    - Identifying hotspots
    - Assessing end of life
    - Etc.
- **Return of Energy investment**

Energy return on investment

Energy return on investment EROI

$$EROI = \frac{energy\ gained}{energy\ invested\ to\ get\ that\ energy} \quad (1)$$

$$EROI > 1\ net\ energy\ supplier$$
$$EROI < 1\ net\ energy\ consumer$$

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Murphy & Hall, (2010). 10.1111/J.1749-6632.2009.05282.X

Energy return on investment EROI

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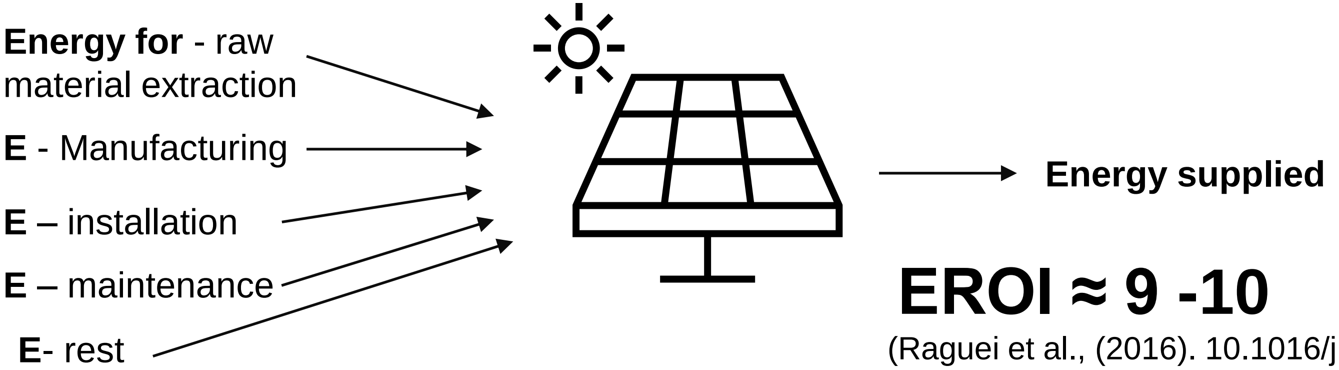

EROI ≈ 9 -10

(Raguei et al., (2016). 10.1016/j.enpol.2016.12.042)

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1 - Murphy & Hall, (2010). 10.1111/J.1749-6632.2009.05282.X

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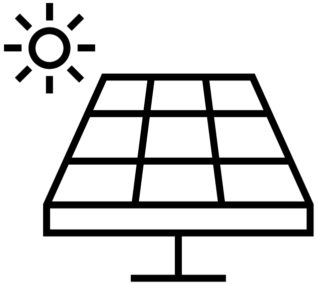
Energy for - raw material extraction

E - Manufacturing

E – installation

E – maintenance

E- rest



Reflect to your lecture journal

What value of EROI would you expect for an energy storage, e.g. a battery?

E

(R

.12.042)

1 - Murphy & Hall, (2010). 10.1111/J.1749-6632.2009.05282.X

Energy return on investment EROI

$$EROI = \frac{energy\ gained}{energy\ invested\ to\ get\ that\ energy} \quad (1)$$

$$EROI = \frac{energy\ discharged}{energy\ invested\ to\ get\ that\ energy + energy\ charged}$$

$$EROI < 1$$

1 - Murphy & Hall, (2010). 10.1111/J.1749-6632.2009.05282.X

Energy stored on energy invested

$$ESOI = \frac{energy\ stored}{energy\ invested\ to\ get\ the\ storage\ device} \quad (2)$$

Energy stored on energy invested

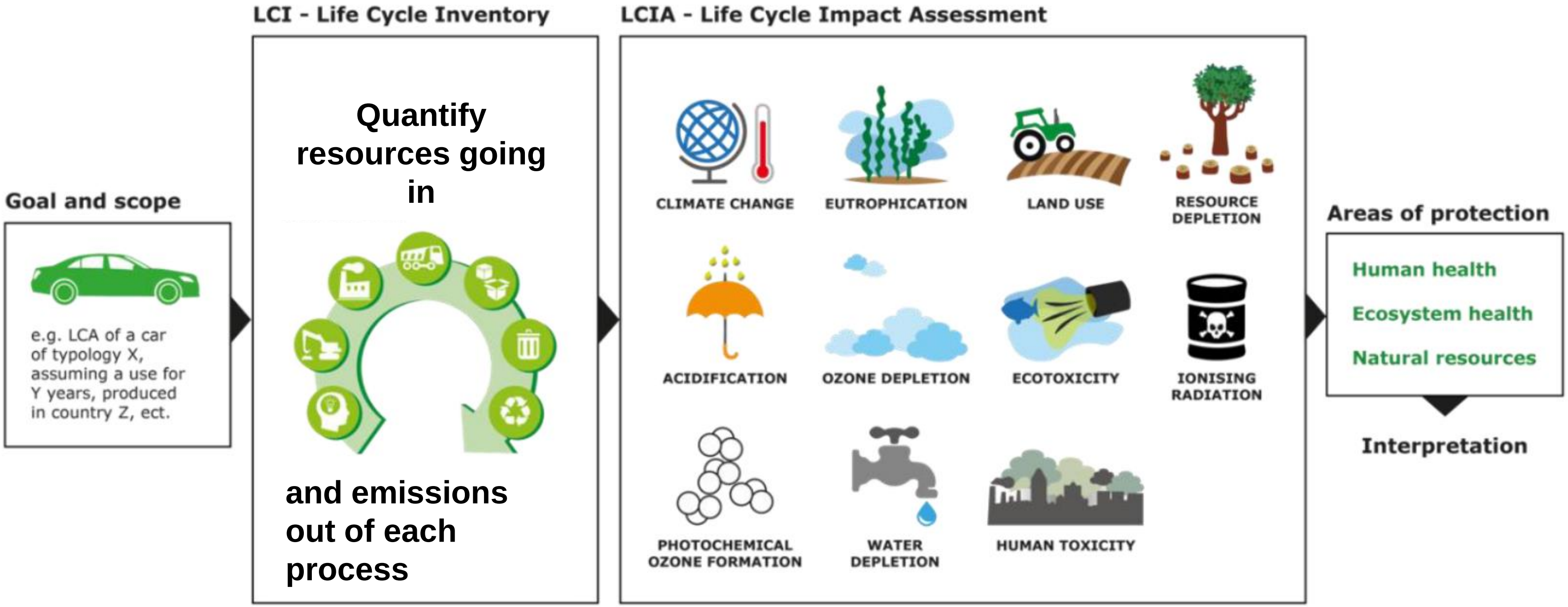
$$ESOI = \frac{energy\ stored}{energy\ invested\ to\ get\ the\ storage\ device} \quad (2)$$

- Accounts for the role of Energy Storages
- ESOI > 1 would indicate net benefit of the storage

Life cycle assessment
… in short

Mandatory parts of LCA

Standard: ISO 14040, ISO 14044



Sala et al., 2016

Goal and scope

Goal definition

- **Intended application of the study**

Goal and scope

Goal definition

- **Intended application of the study**

By providing new inventory data representing the high-end for material and energy use values, but with a potential for reductions, the analysis **indicates a bottom reference level** for **environmental impacts** of large-scale LIB cell production. (Chordia et al., (2021), 10.1038/s41893-019-0222-5.)

Goal and scope

Goal definition

- **Intended application of the study**
- **The reason of carrying LCA**

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The purpose of the study is to **examine the effect of upscaling LIB cell production** from an environmental life cycle perspective. (Chordia et al., 2021, 10.1038/s41893-019-0222-5.)

Goal and scope

Goal definition

- **Intended application of the study**
- **The reason of carrying LCA**
- **To whom do we present it**

By providing new inventory data representing the high-end for material and energy use values, but with a potential for reductions, the analysis **indicates a bottom reference level** for **environmental impacts** of large-scale LIB cell production.

The purpose of the study is to **examine the effect of upscaling LIB cell production** from an environmental life cycle perspective.

[…] LIB production **industry and policy makers** driving action towards decreasing environmental burdens from battery production. The study also aims to inform **LCA practitioners** modelling and analyzing LIBs. (Chordia et al., 2021, 10.1038/s41893-019-0222-5.)

Goal and scope

Scope:

- **Modelling approach**

Goal and scope

Scope:

- Modelling approach
- Functional unit is chosen

- 1kWh of storage capacity
- 1kW of backup capability
- 1 km driven with EV

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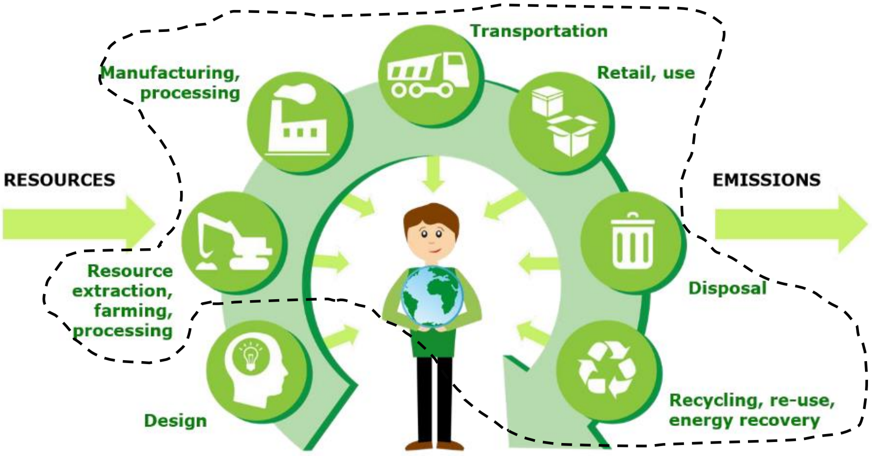
- **System boundaries are defined**



Adopted from Sala et al., 2016. 10.2788/318544

Goal and scope

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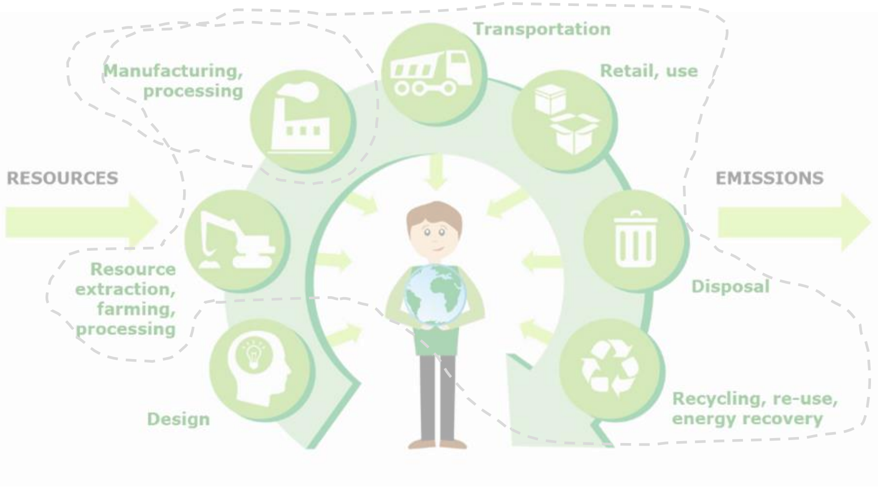
Goal and scope

Scope:

- Modelling approach
- Functional unit is chosen
- System boundaries are defined
- Impacts analyzed
- Level of detail
- List of assumptions
- Data requirements

- 1kWh of storage capacity
- 1kW of backup capability
- 1 km driven with EV



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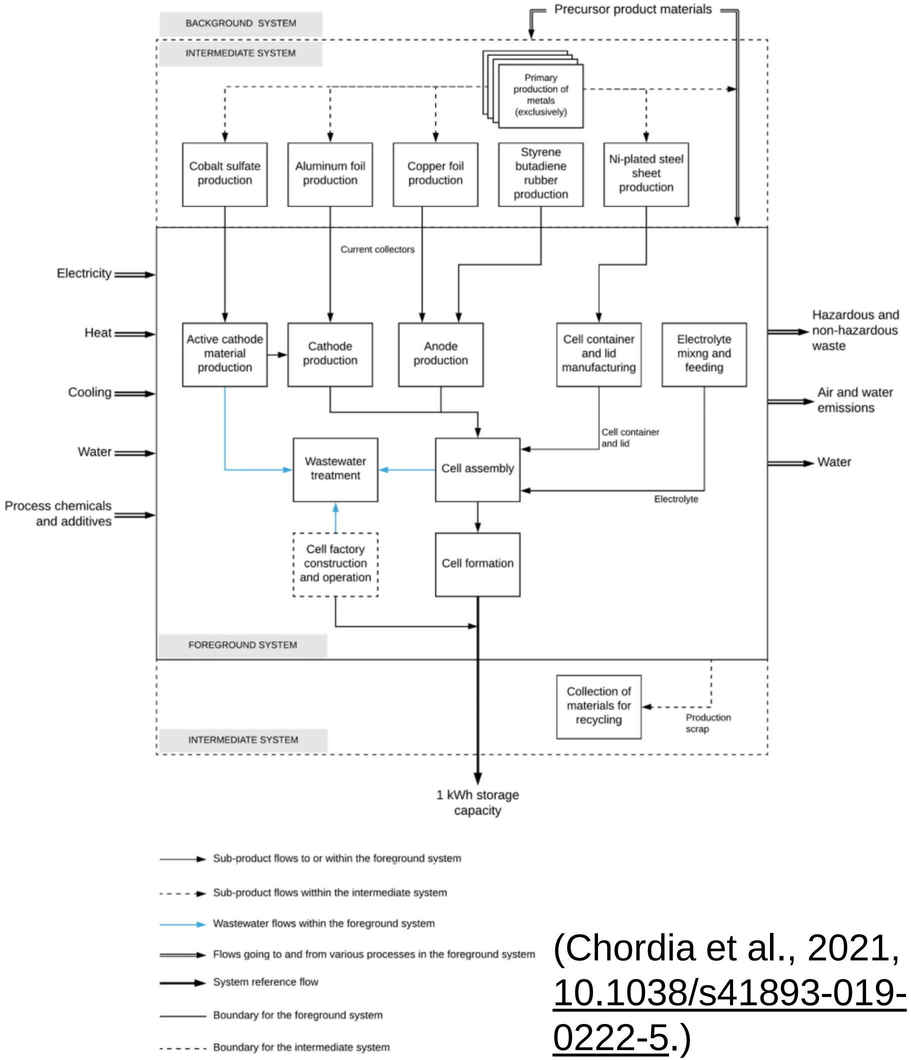
Life cycle inventory

Life cycle inventory

1. **Flow model of the systems based on Goal and Scope**



(Chordia et al., 2021, 10.1038/s41893-019-0222-5.)

Life cycle inventory

1. **Flow model of the systems based on Goal and Scope**
2. **Data collection**

Life cycle inventory

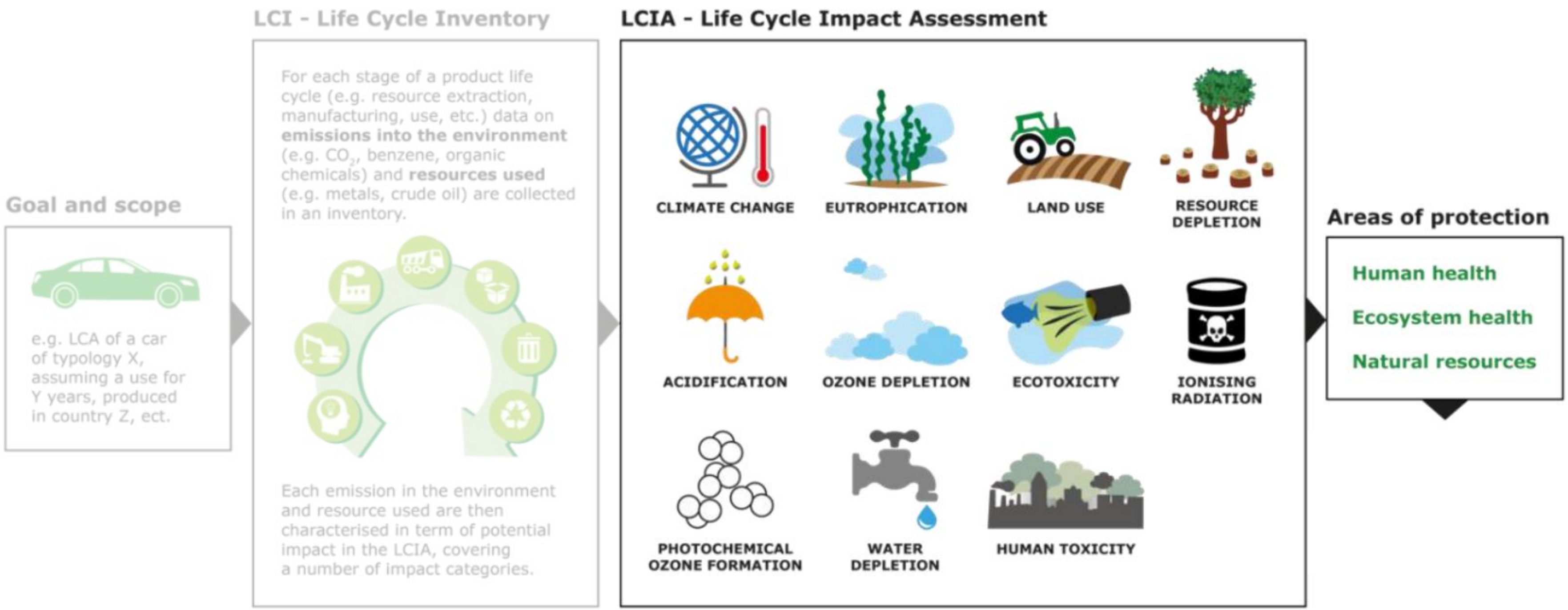
1. **Flow model of the systems based on Goal and Scope**
2. **Data collection**
3. **Calculation of resources needed and emissions generated in relation to the functional unit**

Product material input	Normalized to unit process	Unit
Nickel sulfate	1.54E+00	g
Cobalt sulfate	1.75E-01	g
Manganese sulphate	1.75E-01	g
Lithium hydroxide	2.65E-01	g
Process input	**Normalized to unit process**	**Unit**
Sulphuric acid	9.78E-01	g
Ammonia	2.44E-02	g
Sodium hydroxide	2.00E+00	g
Deionized water	6.75E+01	g
Liquid oxygen	2.44E-01	g
Energy input	**Normalized to unit process**	**Unit**
Electricity	6.21E-03	kWh
Heat	9.32E-04	MJ
Cooling	5.95E-03	MJ
Emission to air	**Normalized to unit process**	**Unit**
Metal dust particles	7.63E-06	g
Wastewater	**Normalized to unit process**	**Unit**
Wastewater, for treatment	6.75E+01	g
Production loss	**Normalized to unit process**	**Unit**
Precursor and active material residues, recyclable	1.50E+00	g
Output	**Normalized to unit process**	**Unit**
Active cathode material	1	g

Chordia et al., (2021).

Life cycle impact assessment

Life cycle impact assesment



Adopted from Sala et al., 2016

LC impact assessment

- **Describe the impacts of the loads quantified in the inventory**

CO_2
CH_4
etc.

SO_2
NO_X
etc.

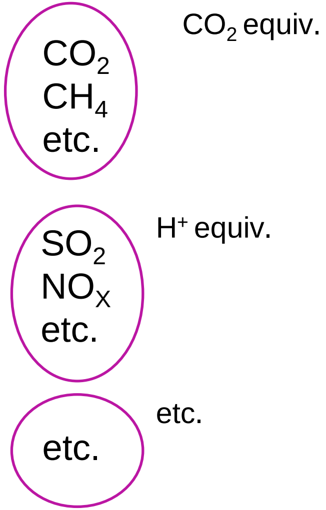
etc.

LC impact assessment

- **Describe the impacts of the loads quantified in the inventory**

Workflow:

1. **Classification**

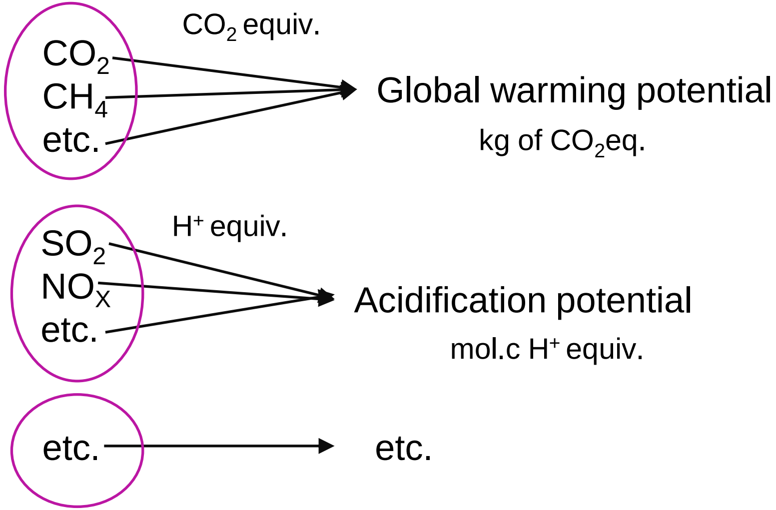


LC impact assessment

- **Describe the impacts of the loads quantified in the inventory**

Workflow:

1. **Classification**
2. **Characterization**



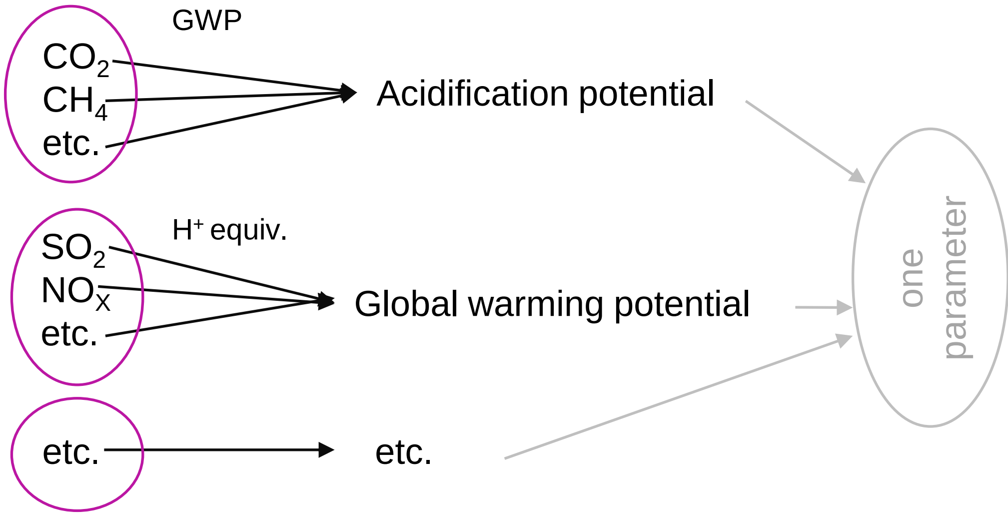
characterization factors

LC impact assessment

- **Describe the impacts of the loads quantified in the inventory**

Workflow:

1. **Classification**
2. **Characterization**
3. **Weighting**



Life cycle impact assessment **interpretation**

Interpretation

Assessing results to draw conclusions in line with the goal and scope

- **Finding the crucial results**
  - Inventory results
  - Impact assessment
- **Presenting the data**

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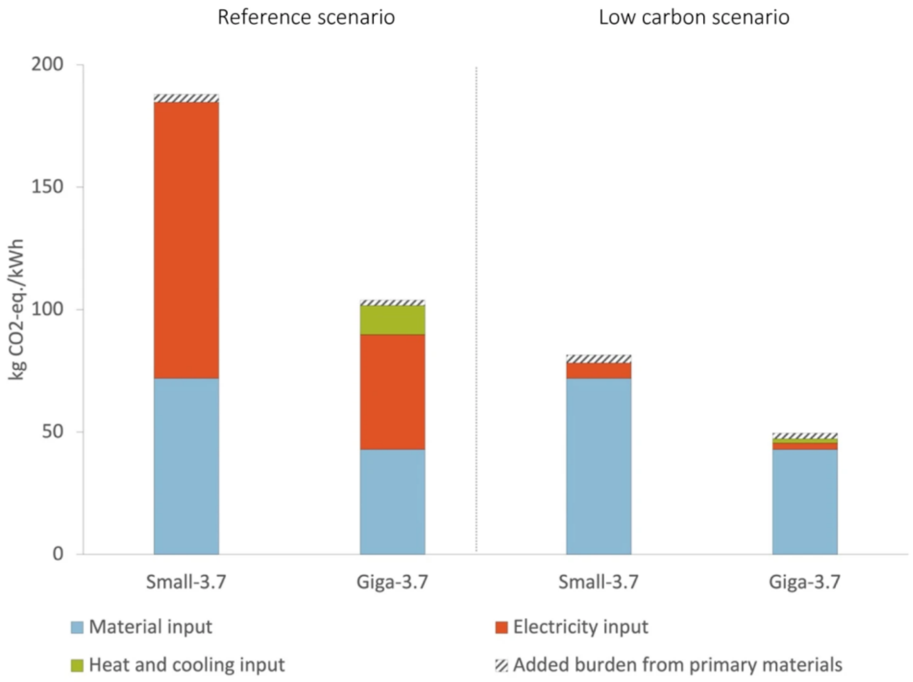


Chordia et al., 2021, 10.1038/s41893-019-0222-5.

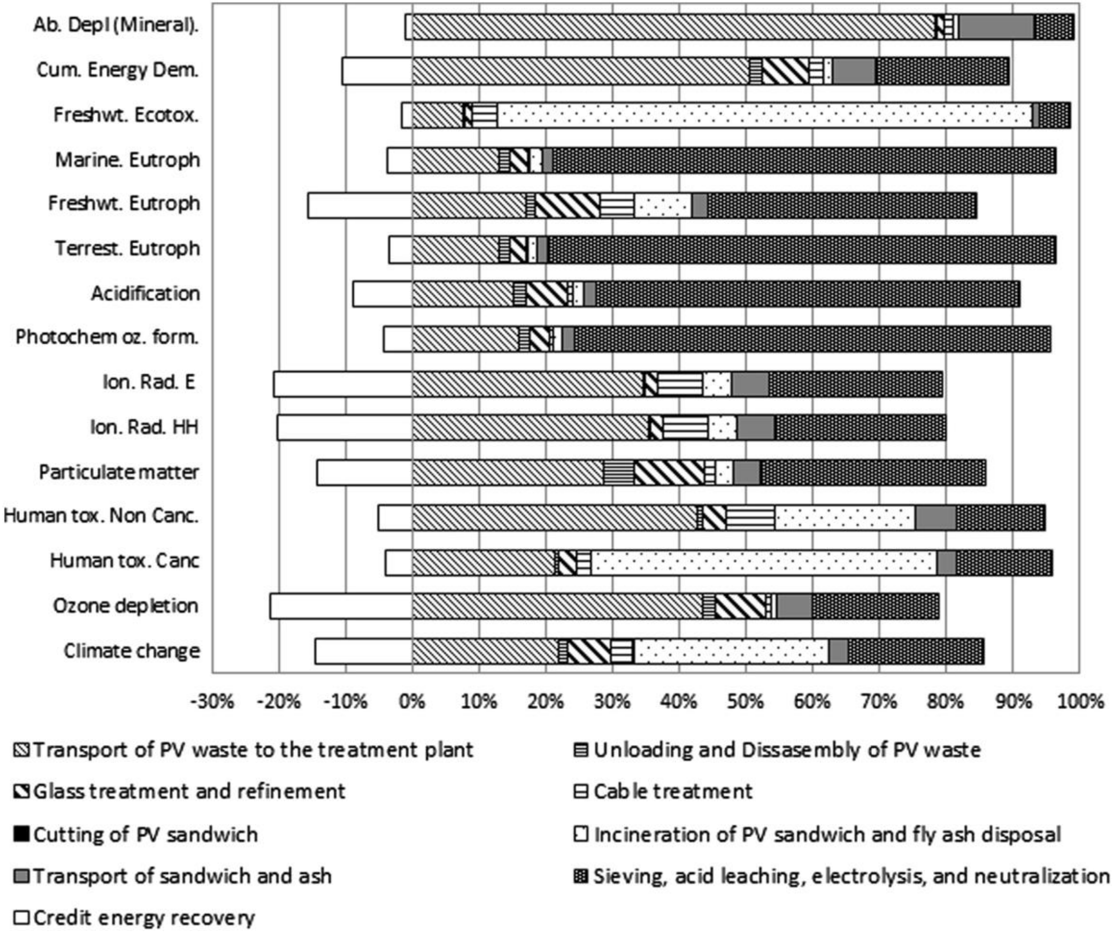
Interpretation

Assessing results to draw conclusions in line with the goal and scope

- **Finding the crucial results**
  - Inventory results
  - Impact assessment
- **Presenting the data**
- **Testing the robustness of the results**
- …

Examples Process

Impact category	Unit	Recycling process
Abiotic Resource Depletion (Mineral)	kg Sb eq	4.36E−03
Cumulative Energy Demand	MJ	3.15E+03
Freshwater ecotoxicity	CTUe	1.33E+03
Marine eutrophication	kg N eq	1.09E+00
Freshwater eutrophication	kg P eq	5.58E−02
Terrestrial eutrophication	molc N eq	1.21E+01
Acidification	molc H+eq	2.68E+00
Photochemical ozone formation	kg NMVOC eq	3.00E+00
Ionizing radiation Ecosystems (E)	CTUe	9.42E−05
Ionizing radiation Human Health (HH)	kg U235 eq	3.05E+01
Particulate matter	kg PM2.5 eq	9.81E−02
Human toxicity, non-cancer effects	CTUh	1.95E−05
Human toxicity, cancer effects	CTUh	2.95E−05
Ozone depletion	kg CFC-11 eq	3.21E−05
Climate change	kg CO2 eq	4.46E+02



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Latunussa et al., (2016). 10.1016/J.SOLMAT.2016.03.020

So this is for the short and simplified introduction

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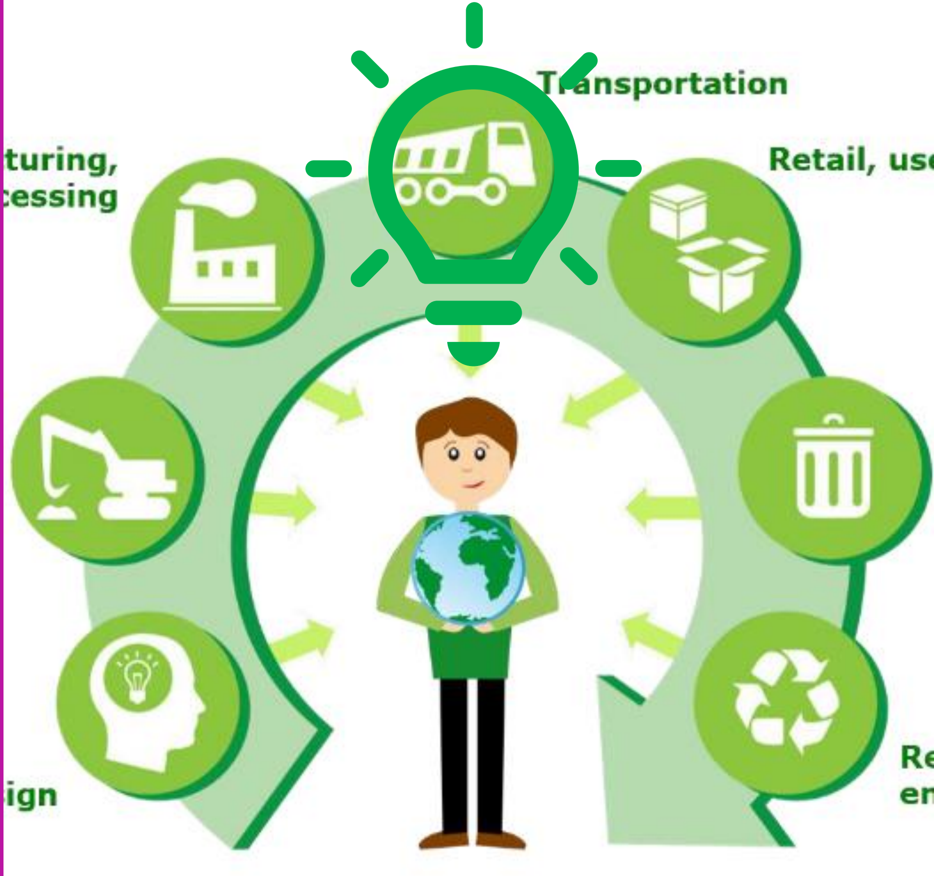
Adopted from Sala et al., 2016

So this is for the short and simplified introduction

Reflect to your lecture journal

What would you pay attention to while comparing two LCA studies and why?



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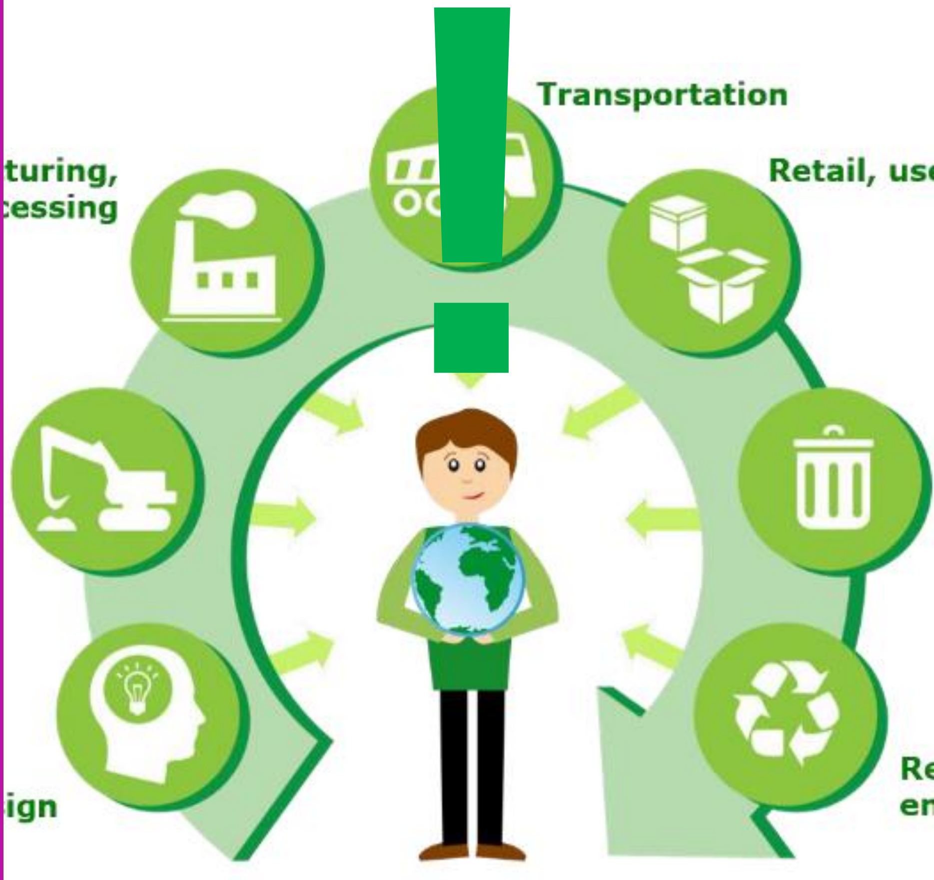
What I think you should pay attention to!

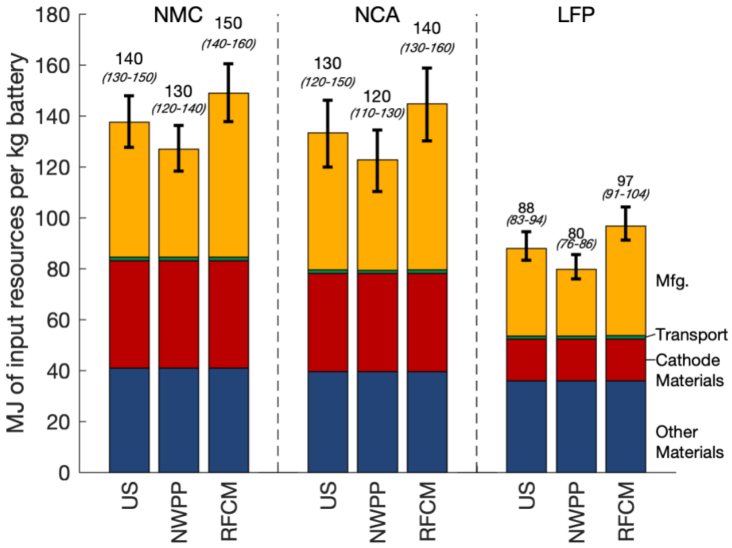


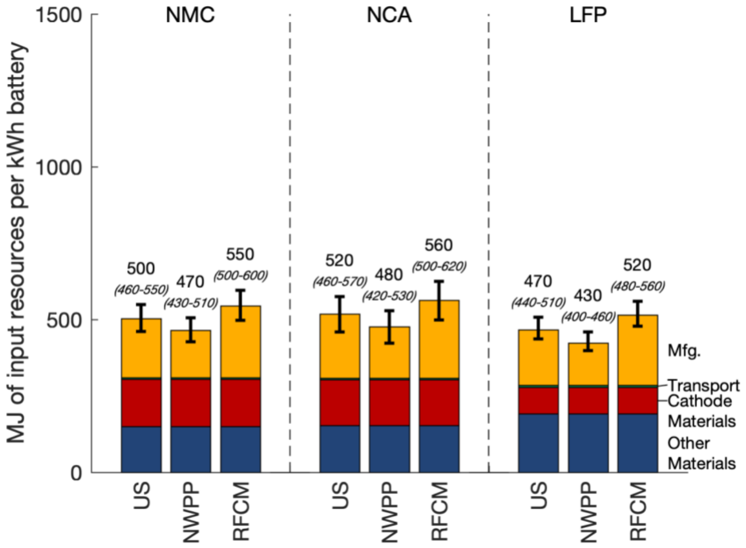
Adopted from Sala et al., 2016

Pay attention to:

Functional unit

- Per kWh, per mass of batteries





median and 95% confidence interval of MJ of energy consumed per kWh or kg of battery while manufacturing NMC, NCA, and LFP pouch cells with US average, NWPP, and RFCM grid emissions (Ciez, R. E., & Whitacre, J. F. (2019). 10.1038/s41893-019-0222-5)

Pay attention to:

Functional unit

- Per kWh, per mass of batteries

System boundaries

- Results, level of detail

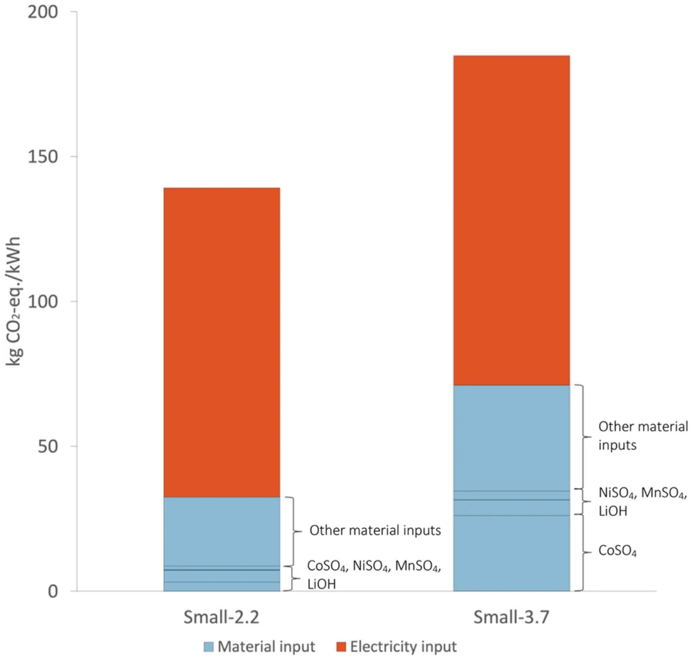
Data

- Industrial data or database, Average or site specific?

Impact assessment method

Varying background data, different results

Variation of database age (Version 2.2 vs. 3.7)



Chordia et al., (2021).

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LCA and EROI

How can we use LCA for EROI

- **Gross energy required/ cumulative Energy demand**
  - Inventory analysis
  - Presented in relation to the functional unit
- **Energy is however only one aspect of the whole story and other LCA impact categories are as important**

Take-home message

Read carefully, be critical and then LCA can be a useful tool in guiding a sustainable design.

References

Ciez, R. E., & Whitacre, J. F. (2019). Examining different recycling processes for lithium-ion batteries. Nature Sustainability 2019 2:2, 2(2), 148–156. https://doi.org/10.1038/s41893-019-0222-5

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