SPEAKER MENG-JU HSIEH

COMPANY CHALMERS UNIVERSITY OF TECHNOLOGY

TOPIC

E-MACHINE DESIGN FOR ENHANCED RECYCLABILITY AND MINIMISED ENVIRONMENTAL IMPACT

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E-machine design for enhanced recyclability and minimised environmental impact

PhD student: Meng-Ju Hsieh

Supervisors:

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Sonja Lundmark, Anders Nordelöf

Outline

- Introduction to LCA
- Previous E-machine LCA work
- PhD project

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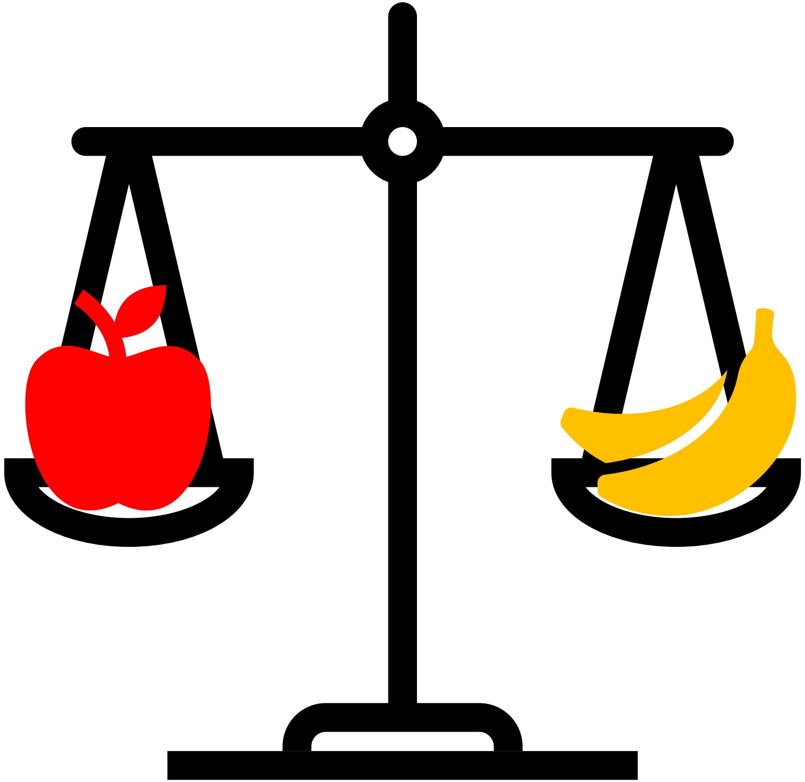
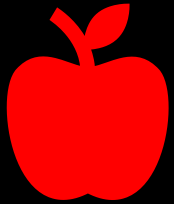
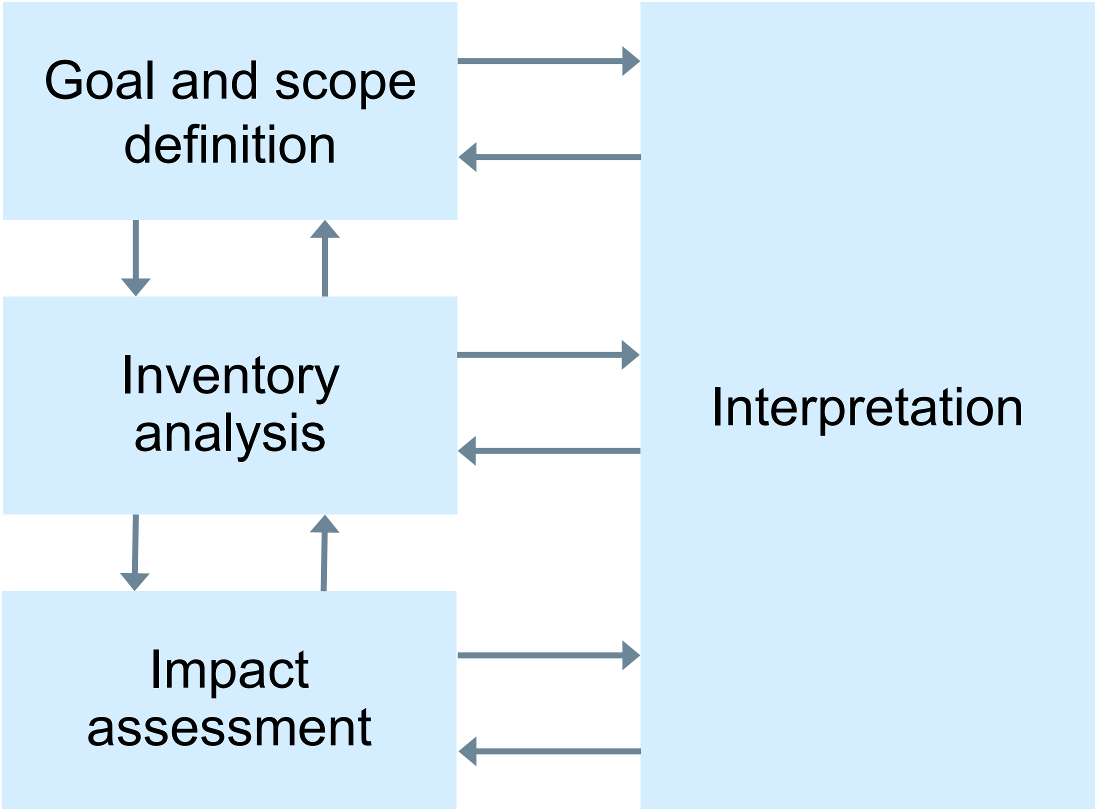
Introduction to Life Cycle Assessment (LCA)

Why LCA?

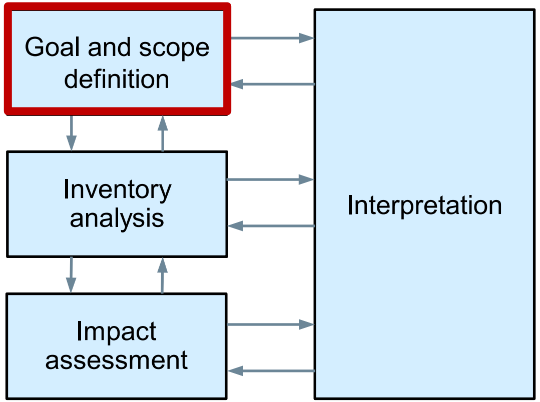


Index		
Economic	29,90 kr/kg	28,90 kr/kg
Nutritional	520 kcal/kg	880 kcal/kg
Environmental	?	?

LCA framework

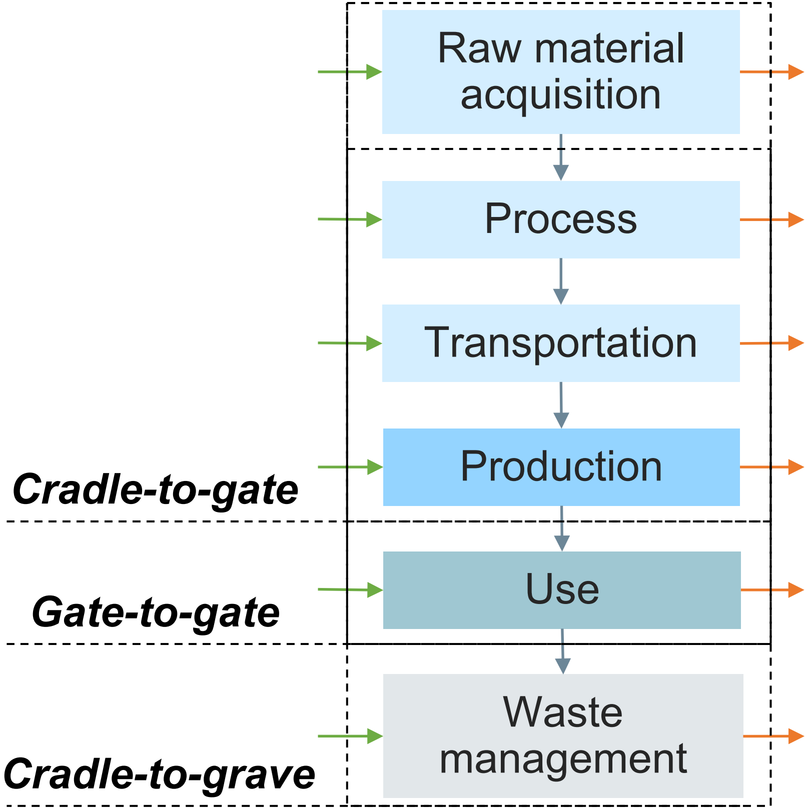


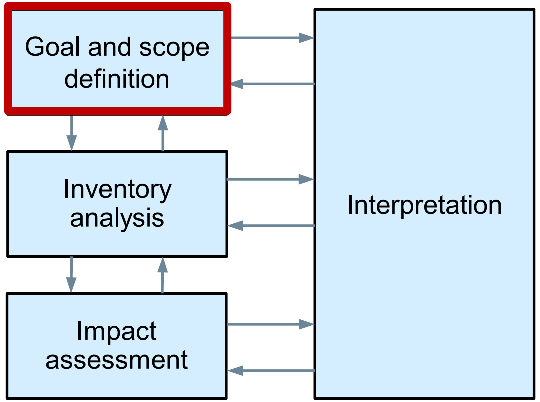
Goal and scope definition



- The goal
  - Why - reason, intended application
  - Who - intended audience
  - What - product/system
  - Purpose - specified question
- The scope
  - Functional unit
  - Impacts and how to describe them
  - System boundaries and initial flow chart
  - Data quality requirements

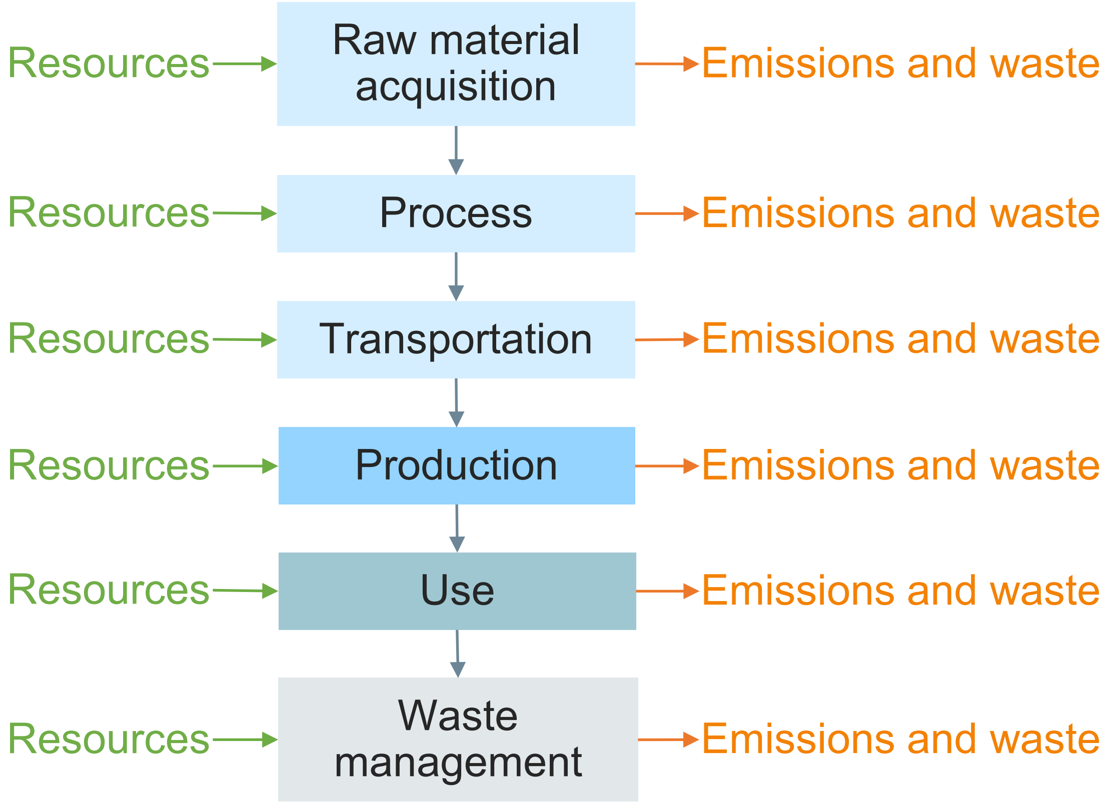
Scope - Life cycle model

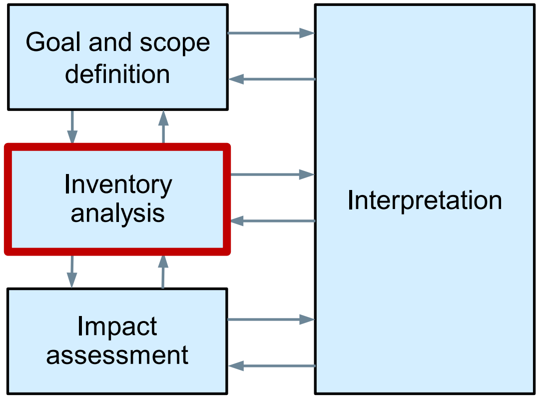




- Functional unit, eg: **kg-apple, kcal-banana**
- Impacts, eg: **resource use**, **human health**
- System boundaries and initial flow chart
- Data quality requirements

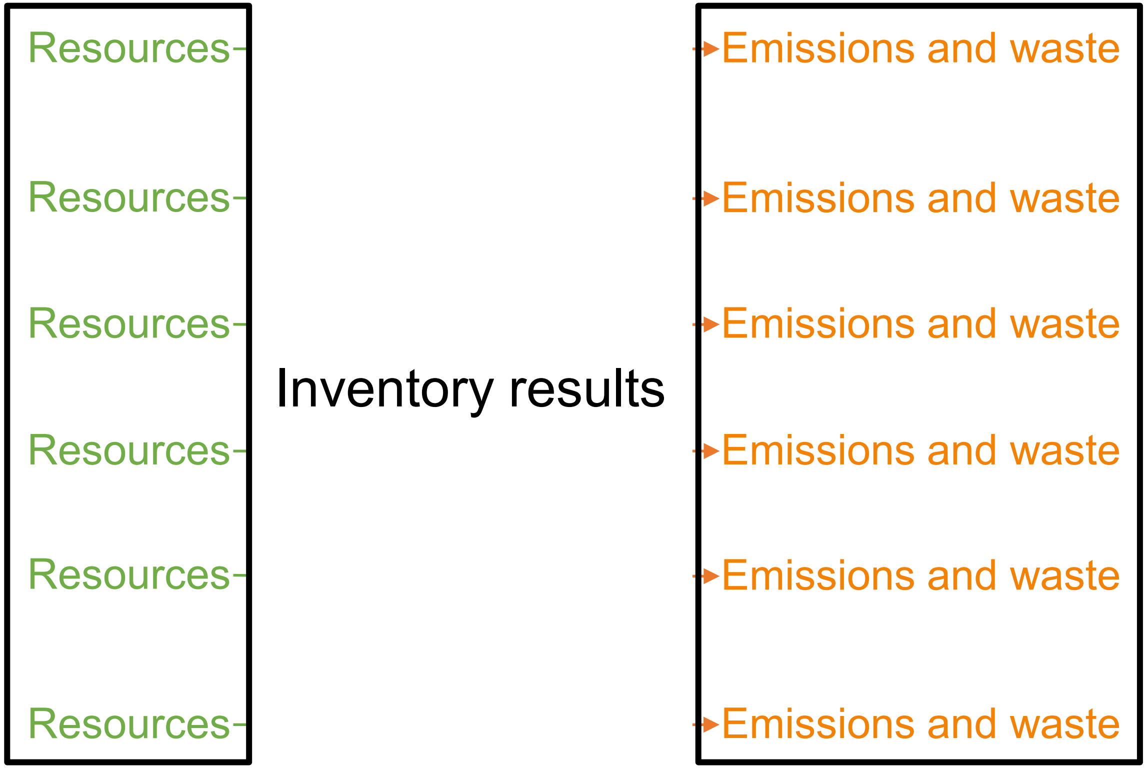
Inventory Analysis (LCI)

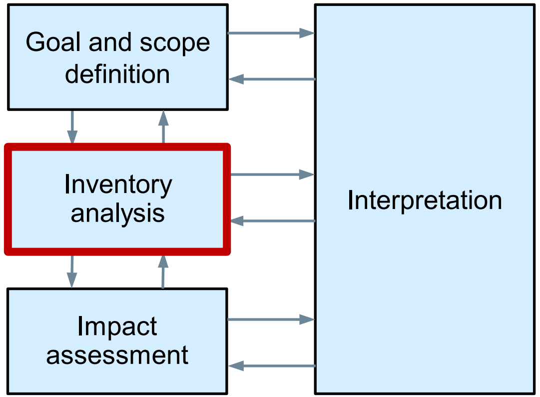




- Construction of flow model
    - boxes and arrows
- Data collection
    - raw materials (incl. energy)
    - Emissions and waste

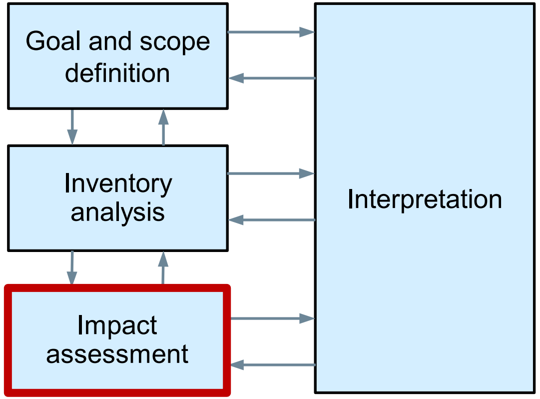
Inventory Analysis (LCI)

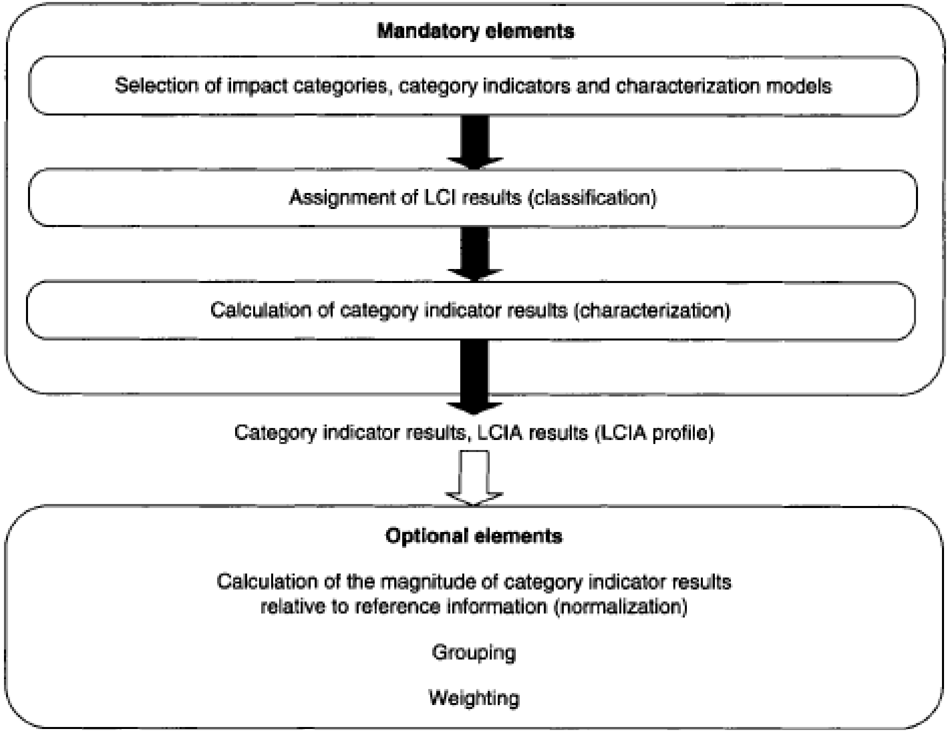




- Calculation
  - product flows (systems equations)
  - elementary flows, scaled to the functional unit, eg: **kg water/kg-apple**, **g CH4/kcal-banana**…

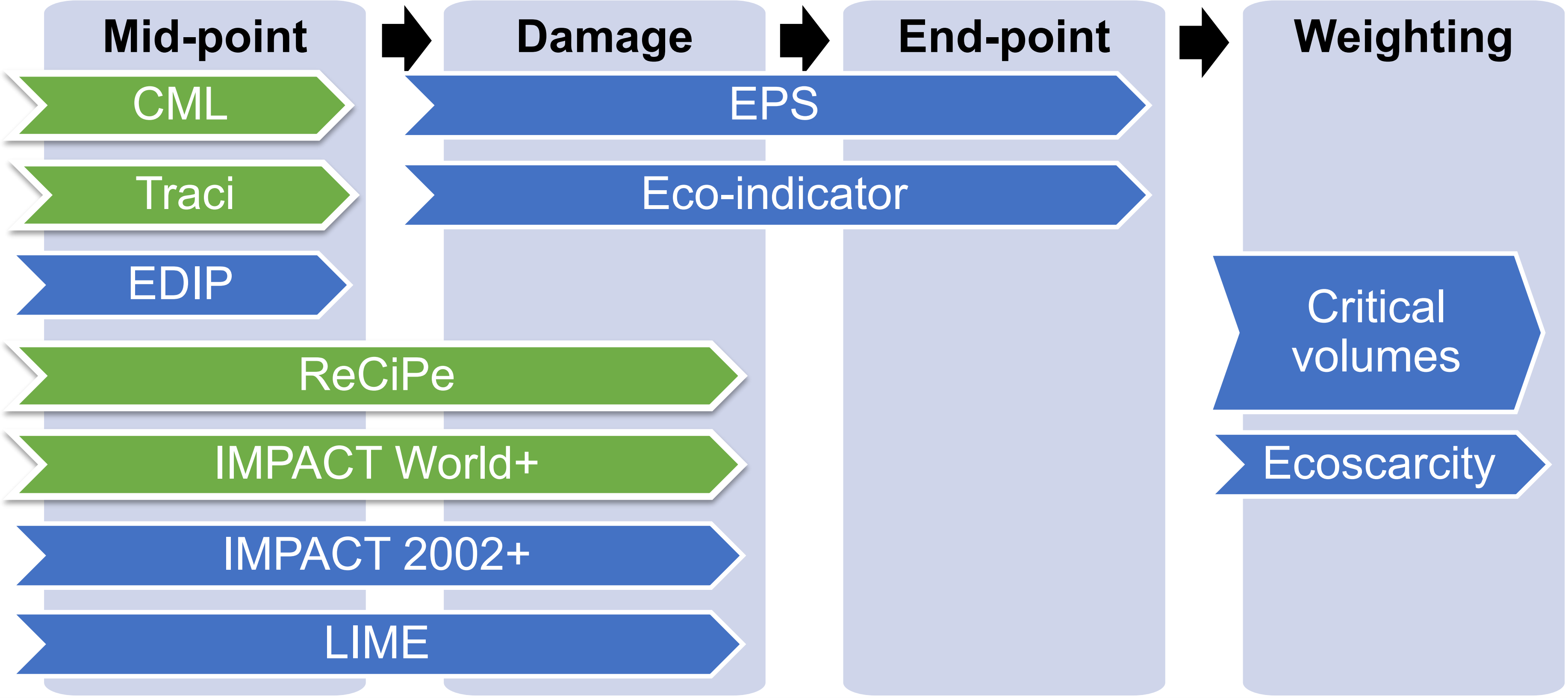
Life cycle impact assessment (LCIA)

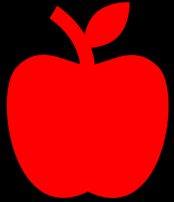




- Key impact categories:
  - Global warming
  - Water use
  - Toxicity for chemicals
  - Energy use for fuels

Ready-made LCIA methods



Index		
Economic	29,90 kr/kg	28,90 kr/kg
Nutritional	520 kcal/kg	880 kcal/kg
Environmental*	0.185 kg CO2-eq/kg 0.356 g CO2-eq/kcal (Sweden)	0.294 kg CO2-eq/kg 0.334 g CO2-eq/kcal (Sweden)

*Karlsson, A. E., Climate Impact from Fresh Fruit Production, 2017.

Uses of LCA

- Decision making
  - Product/process development
  - Purchase & supply chain management
  - Environmental policy making
- Learning
  - Identification of improvement possibilities
  - Formulation of rules-of-thumb
  - Risk management
- Communication
  - eco-labelling
  - environmental product declarations
  - footprints
  - reporting
  - green product portfolios

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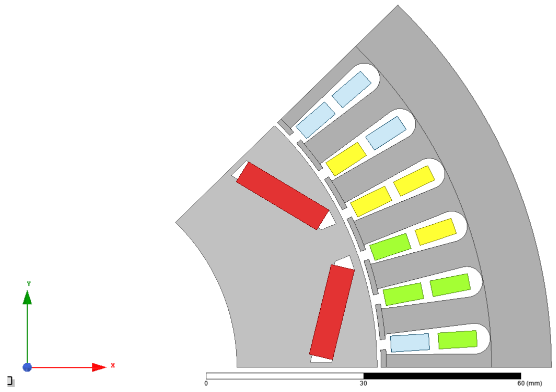
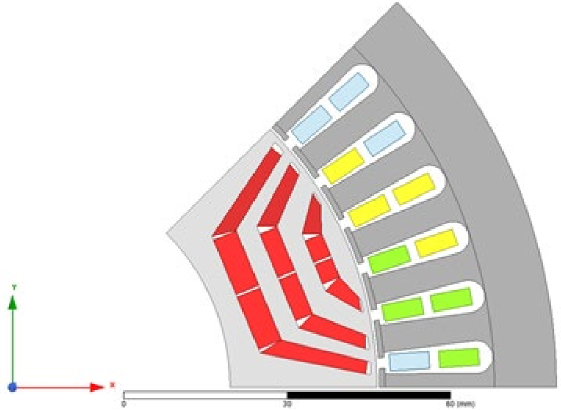
Previous E-machine LCA Work

Goal



PMSM



PMaSynRM

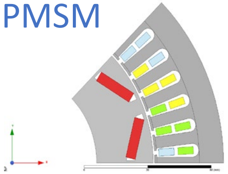
Rotor Configuration	Magnet
PMSM	Nd (Dy) FeB
PMSM	SmCo
PMaSynRM	Sr-ferrite

Benchmarking

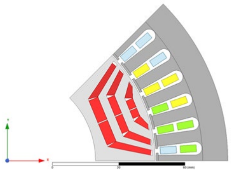
Scope of previous work

EM design

SmCo PMSM

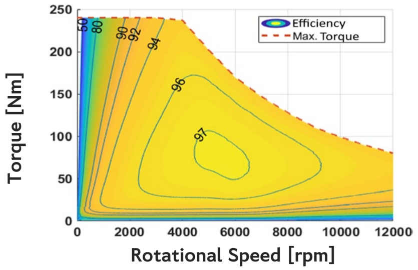


Sr-Ferrite PMaSynRM



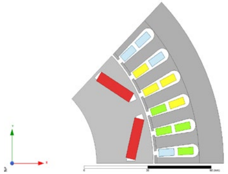
Material use [kg]

Efficiency map

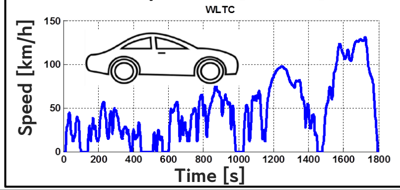


Benchmarking:

Nd(Dy)FeB PMSM



Drive cycle electricity consumption [kWh]



production side

users' side

E-machine LCA

Raw material acquisition

Process

Transportation

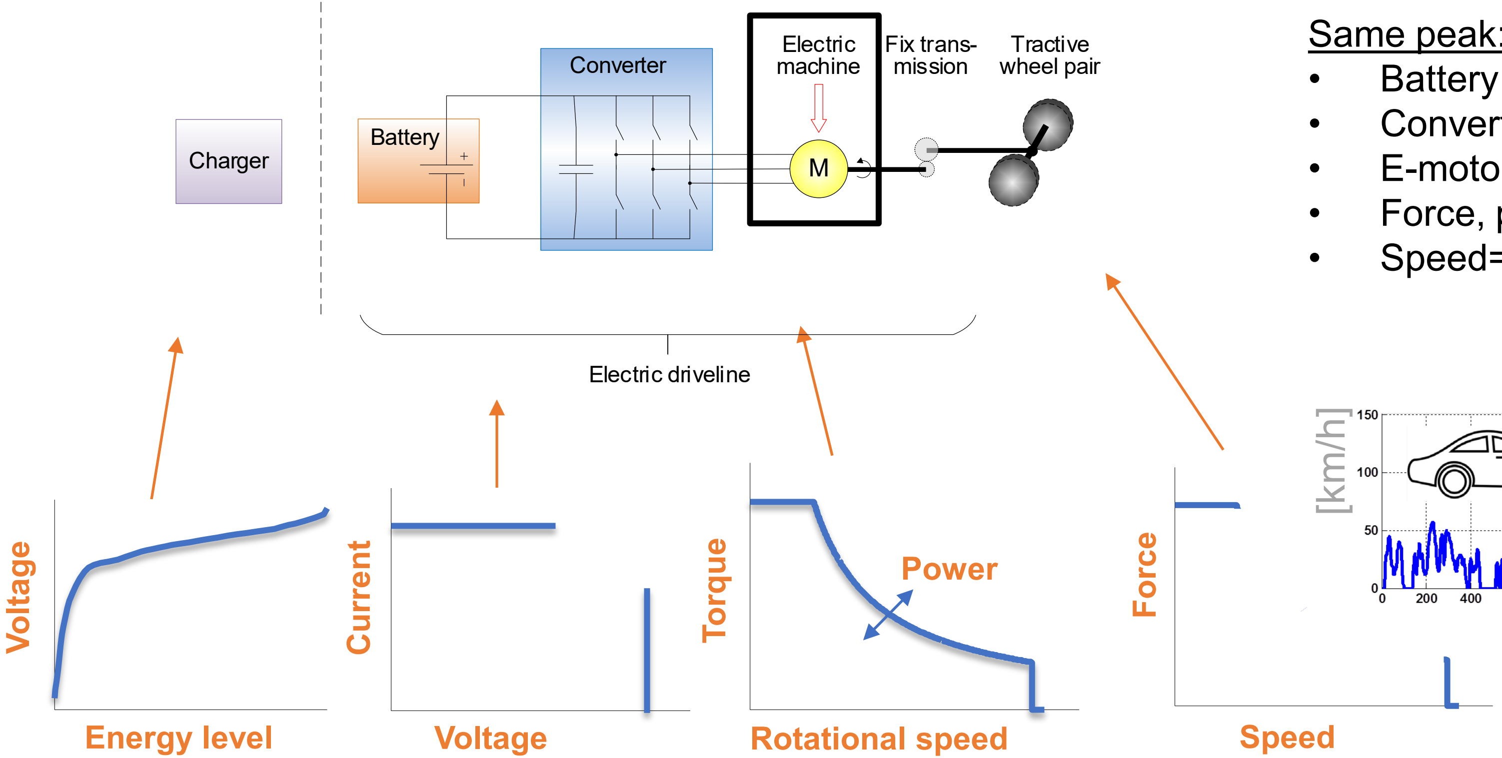
Motor factory

Use

Waste management

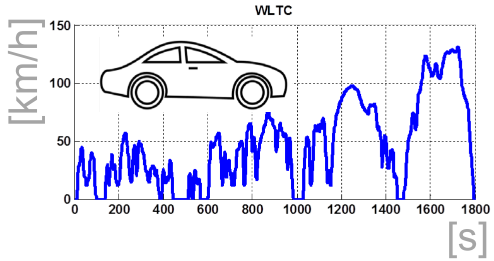
Emissions and waste

Boundary conditions of E-machine

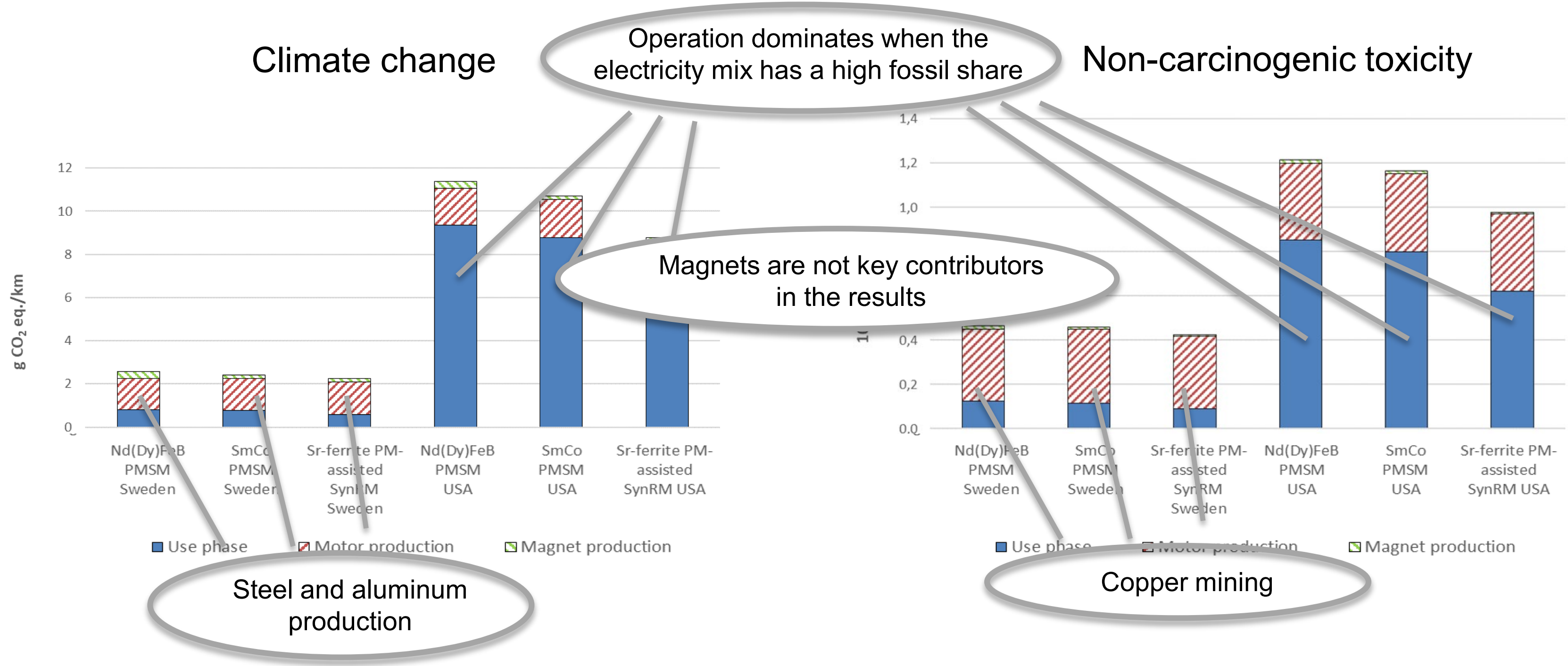


Same peak:

- Battery voltage
- Converter current
- E-motor outer diameter
- Force, power to wheels
- Speed=> same gear



Results



Anders Nordelöf, Chalmers, 2020-10-12

Conclusions

- Impacts on climate change and human toxicity most important
- PMaSynRM causes lowest CO2 emissions – interesting for further investigations
- Mining and production of copper is a major contributor of toxic emissions
- Magnets contribute to the burden, but mostly indirect
- Recommended motor design targets
  - high energy efficiency
  - slender housings
  - compact end-windings
  - segmented laminates

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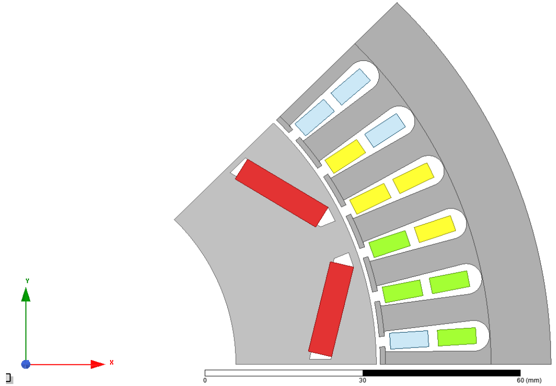
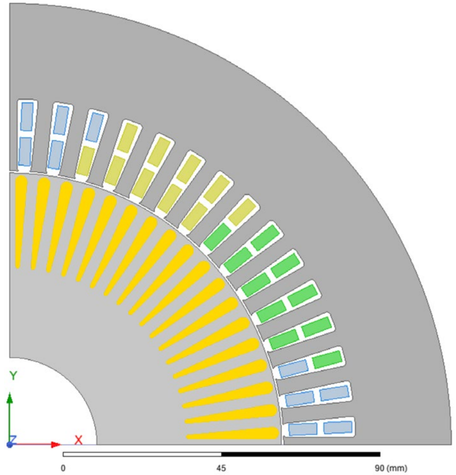
PhD Project
(Follow-up LCA work)

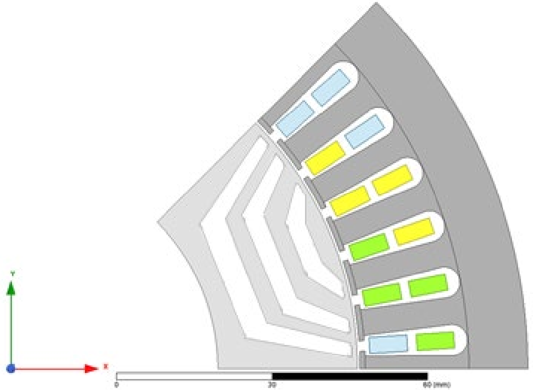
Goal



PMSM



IM



SynRM

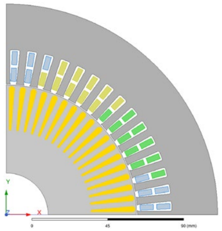
Rotor Configuration	Magnet
PMSM	Nd (Dy) FeB
IM	-
SynRM	-

Benchmarking

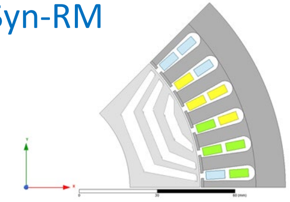
Scope

EM design (REE free)

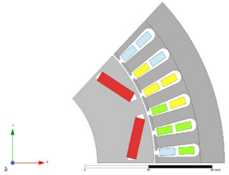
IM



Syn-RM

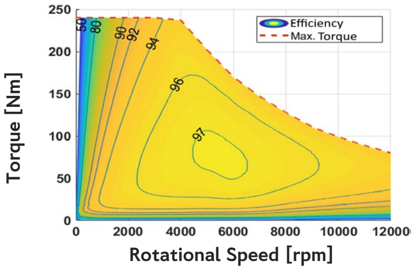


Benchmarking:
Nd(Dy)FeB PMSM

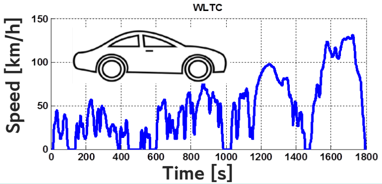


Material use [kg]

Efficiency map



Drive cycle electricity consumption [kWh]

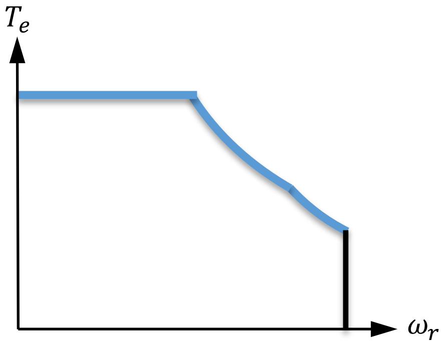


E-motor LCA

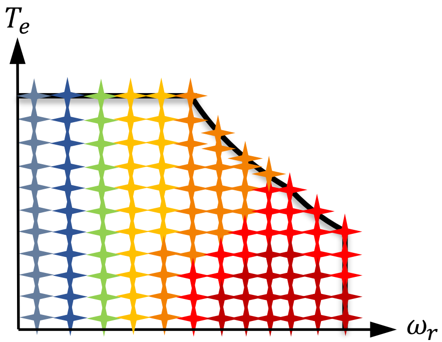
- Raw material acquisition
- Process
- Transportation
- Motor factory
- Use
- Waste management

Emissions:
- air
- water
- ground

IM efficiency map calculation



Step 1



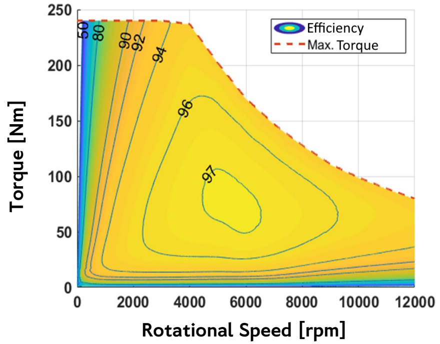
Step 2

Optimal control

Require:

- Algorithm development
- Electrical parameter identification

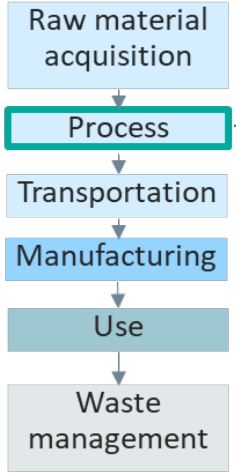
Efficiency

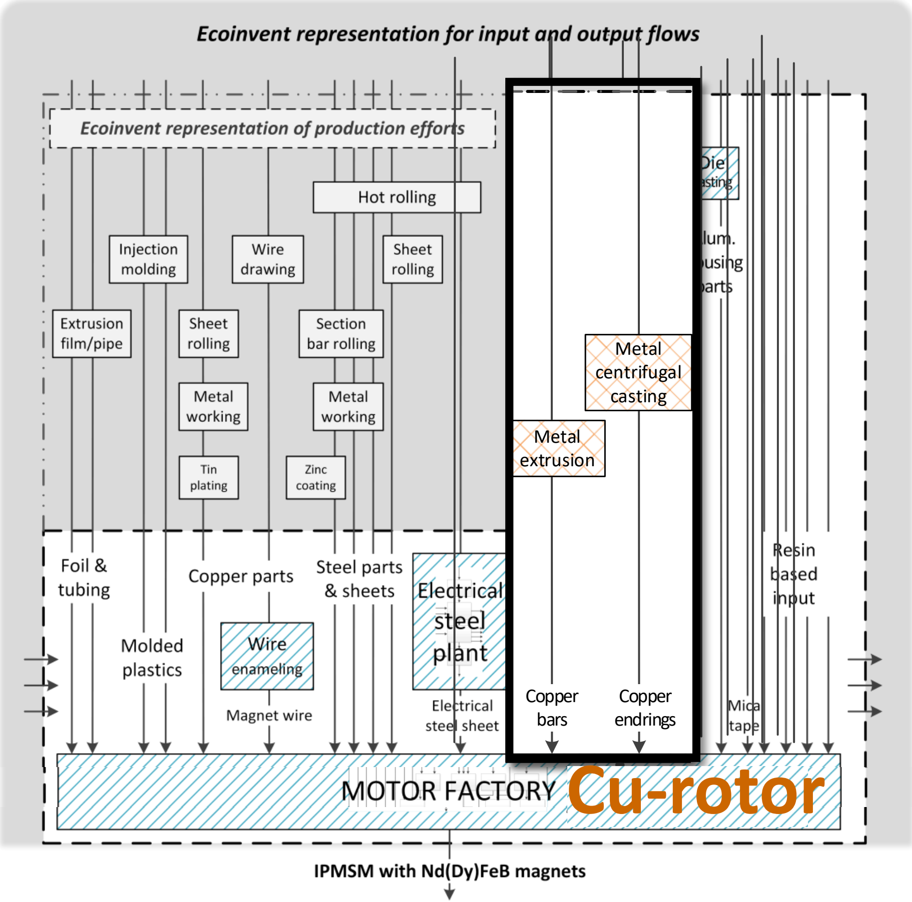


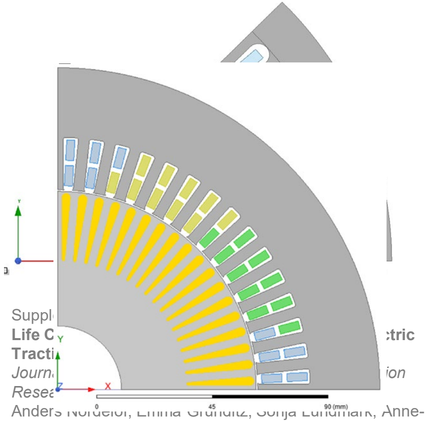
Step 3

Determine energy losses

System Boundary

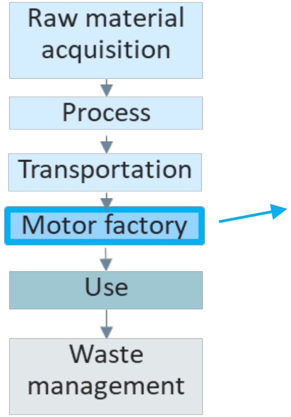


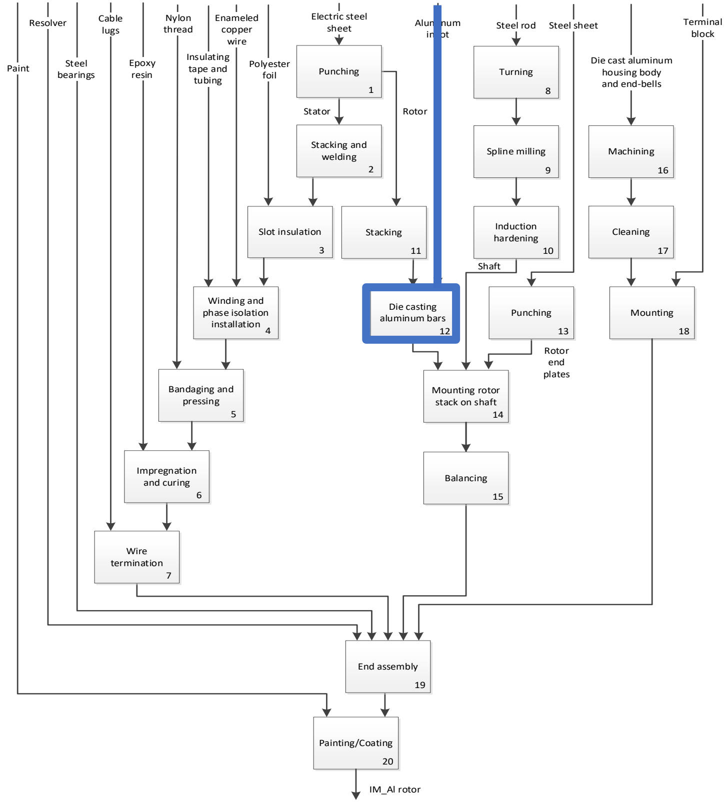


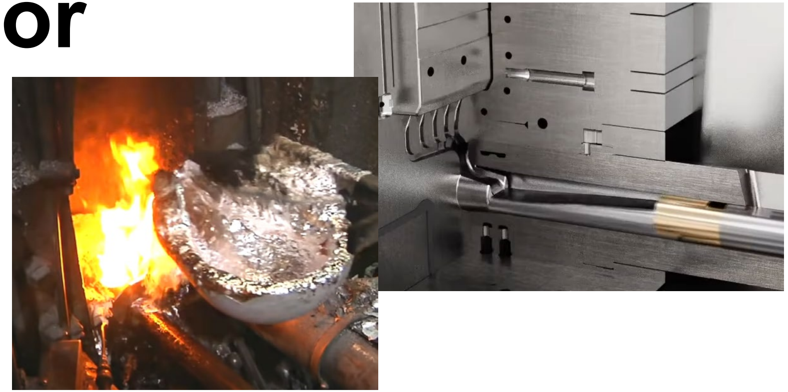


Suppl…
Life C… …tric
Tracti…
Journ… …ion
Resea…
Anders Nordelöf, Emma Grunditz, Sonja Lundmark, Anne-Marie Tillman, Mikael Alatalo, Torbjörn Thiringer

IM Motor Factory - Al-rotor



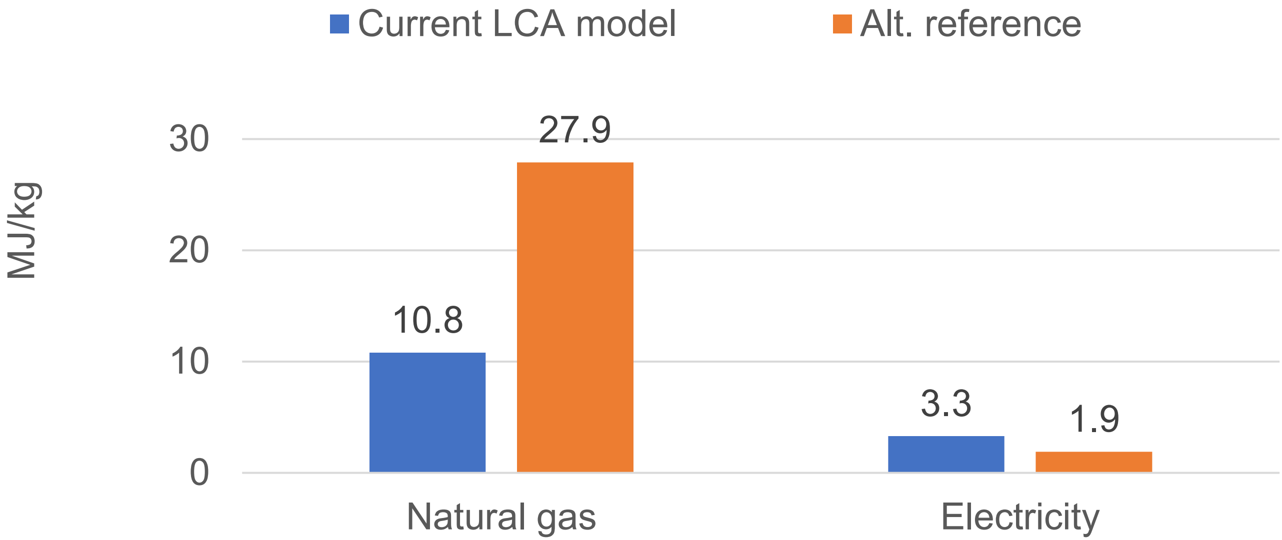




High pressure die casting (HPDC)

- Similar process as for Al-housing
- Re-use LCA model
- Melting process:
  - Conventional: natural gas
  - Potential update: electricity

Al HPDC Energy to melt aluminum



Just melting Al. from 20°C to 660°C require ≈ 1 MJ/kg

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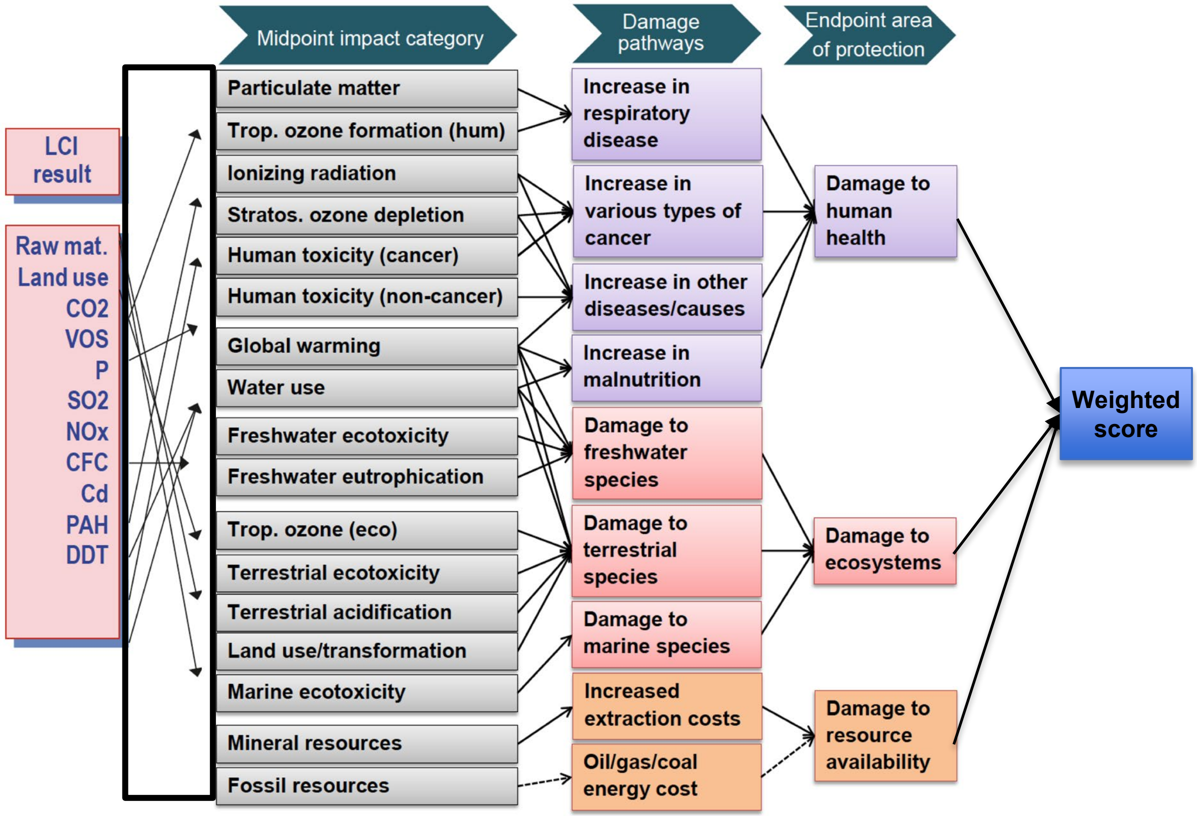
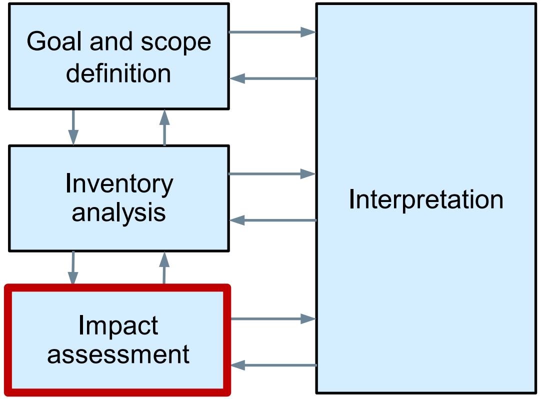
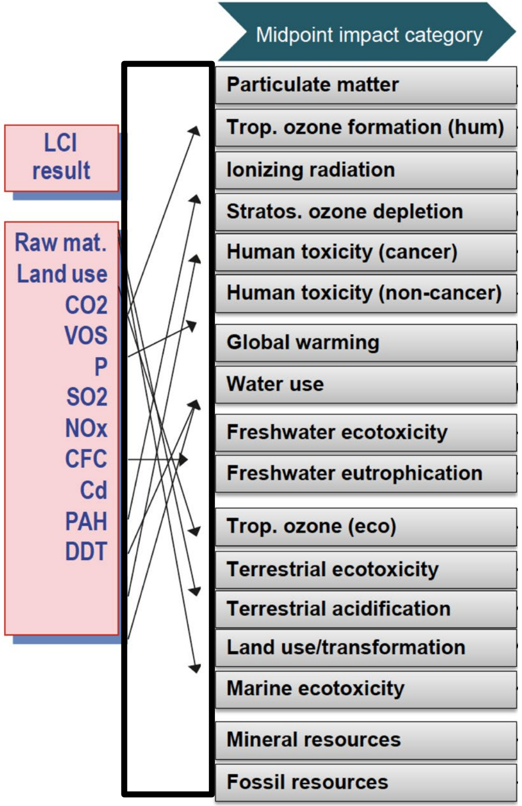
Thank you

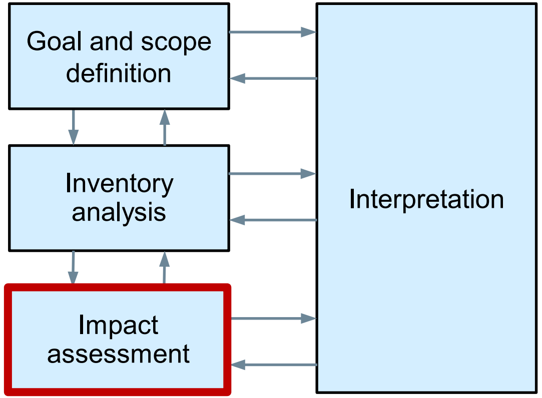
ReCiPe impact categories





ReCiPe impact categories





- LCIA equation:

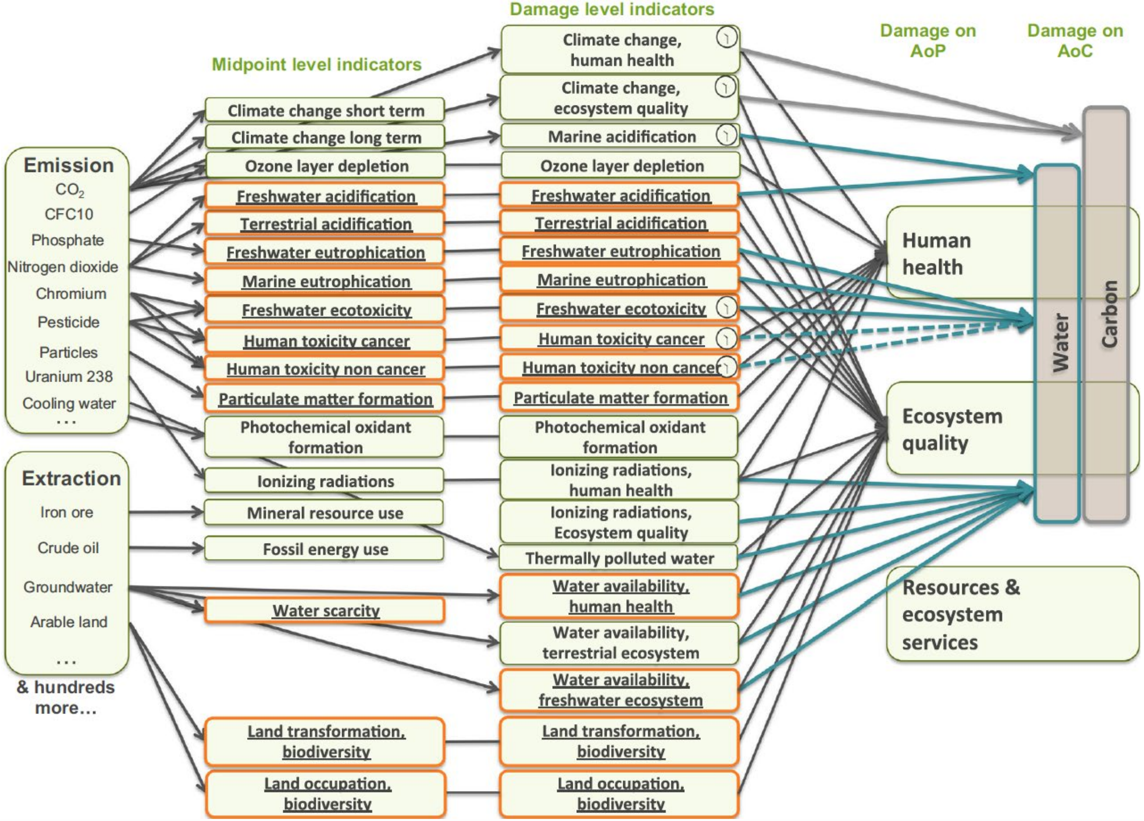
$$IS_j = \sum_i Q_i \times CF_{i,j}$$

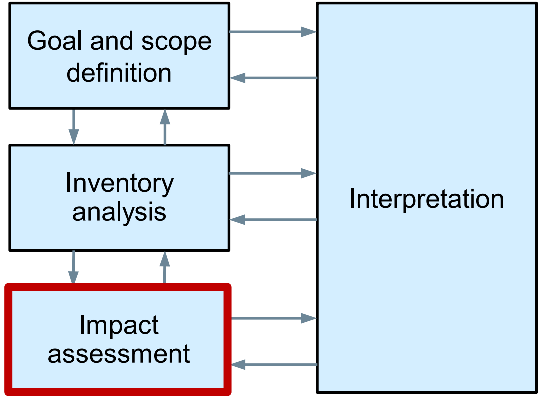
IS_j: impact score for impact category j

Q_i: quantity of elementary flow i (emission or resource use, inventory results)

$CF_{i,j}$: characterisation factor for elementary flow i to impact category j

IMPACT World+





Reference E-machine – PMSM

E-motor	Car
Max power	100 kW
Max torque	239 Nm
Max rot. Speed	12 000 rpm
Max dc-voltage	430 V
Max rms ph. Current	260 A
Max rms current density	20 A/mm^2
Stator outer diameter	200 mm
Stator length	127 mm