Eco-conscious design evaluation of Airborne Wind Energy Systems (drag power kite) using Life Cycle Assessment

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Flying wind turbines.

Outline

- LCA design tool at TU-Munich
- AWES Kitekraft GmbH
- Sizing model and LCA implementation
- Results & conclusions
- Future work

Picture: Kitekraft GmbH

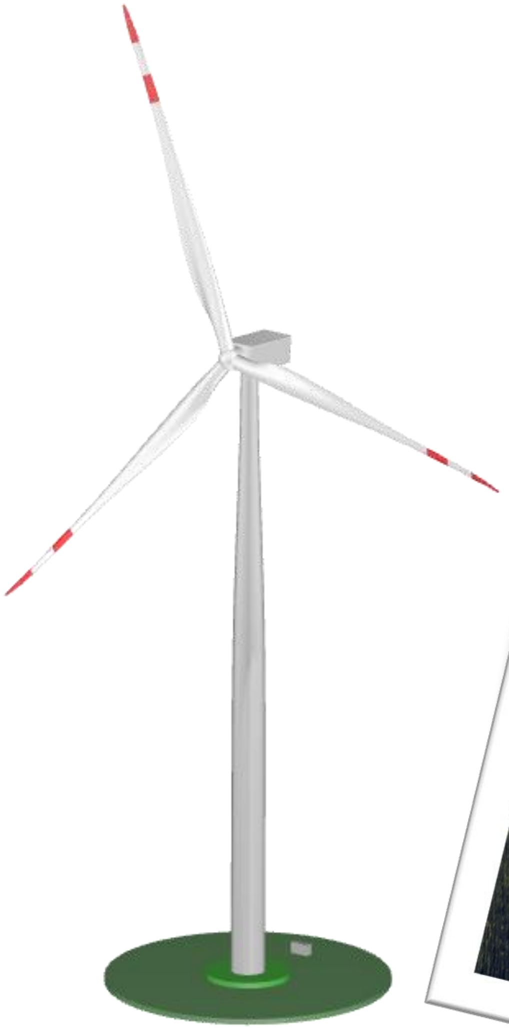
LCA design tool at TU-Munich

Motivations:

- "**Eco-conscious design**": *now that wind energy is competitive, how can we increase its value for the environment and for society?*

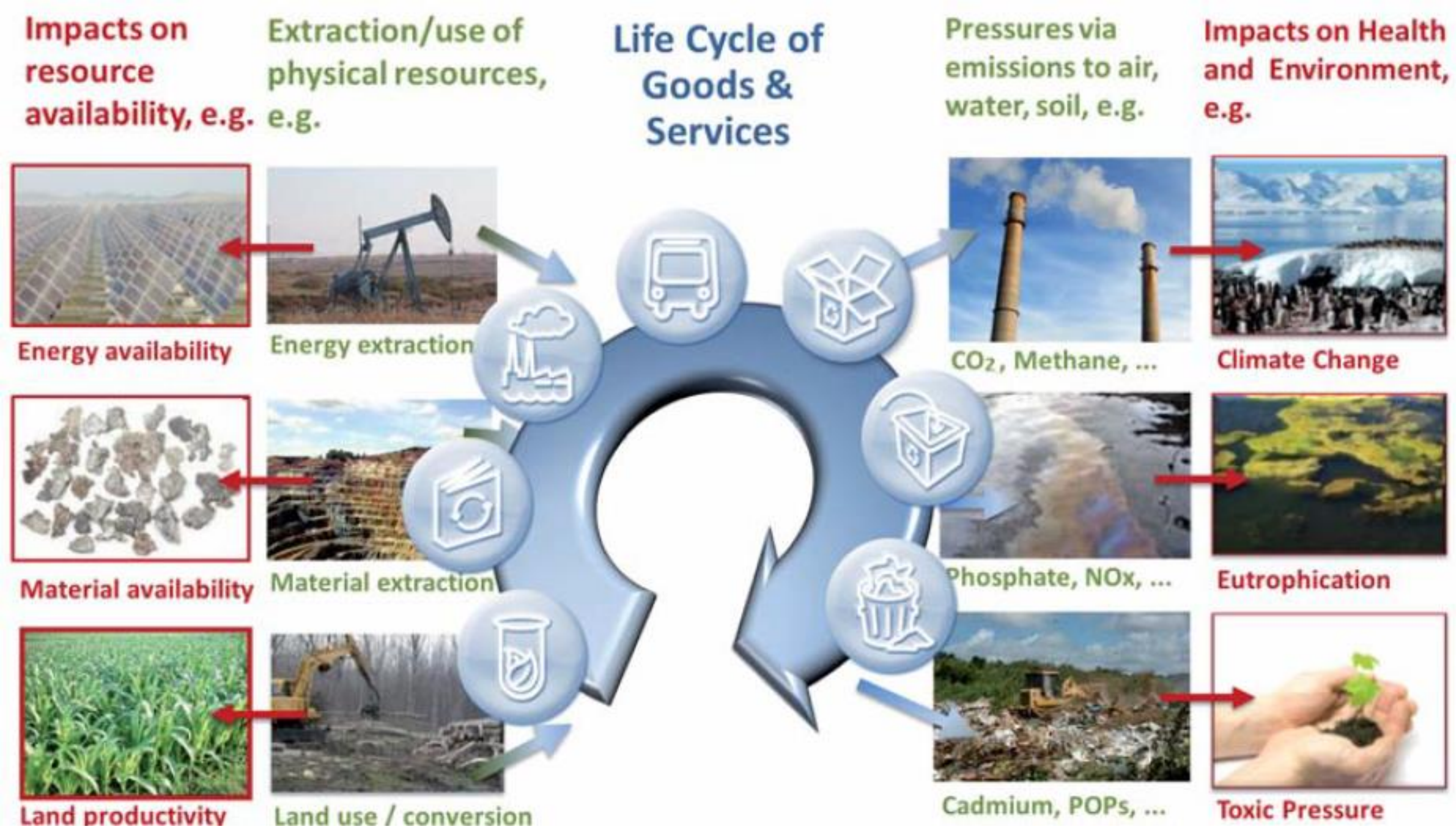
$COE_{€} \rightarrow COE_{CO_2}$

- Link a **life-cycle assessment (LCA) model** in the design phase, to minimize the carbon footprint (in gCO2eq/kWh)
- **AWES** has a huge potential for **low COE_{CO_2}**, due to reduced material consumption



Pictures: IEA Task 37 3.35MW turbine, Kitekraft GmbH

Life-Cycle Assessment:



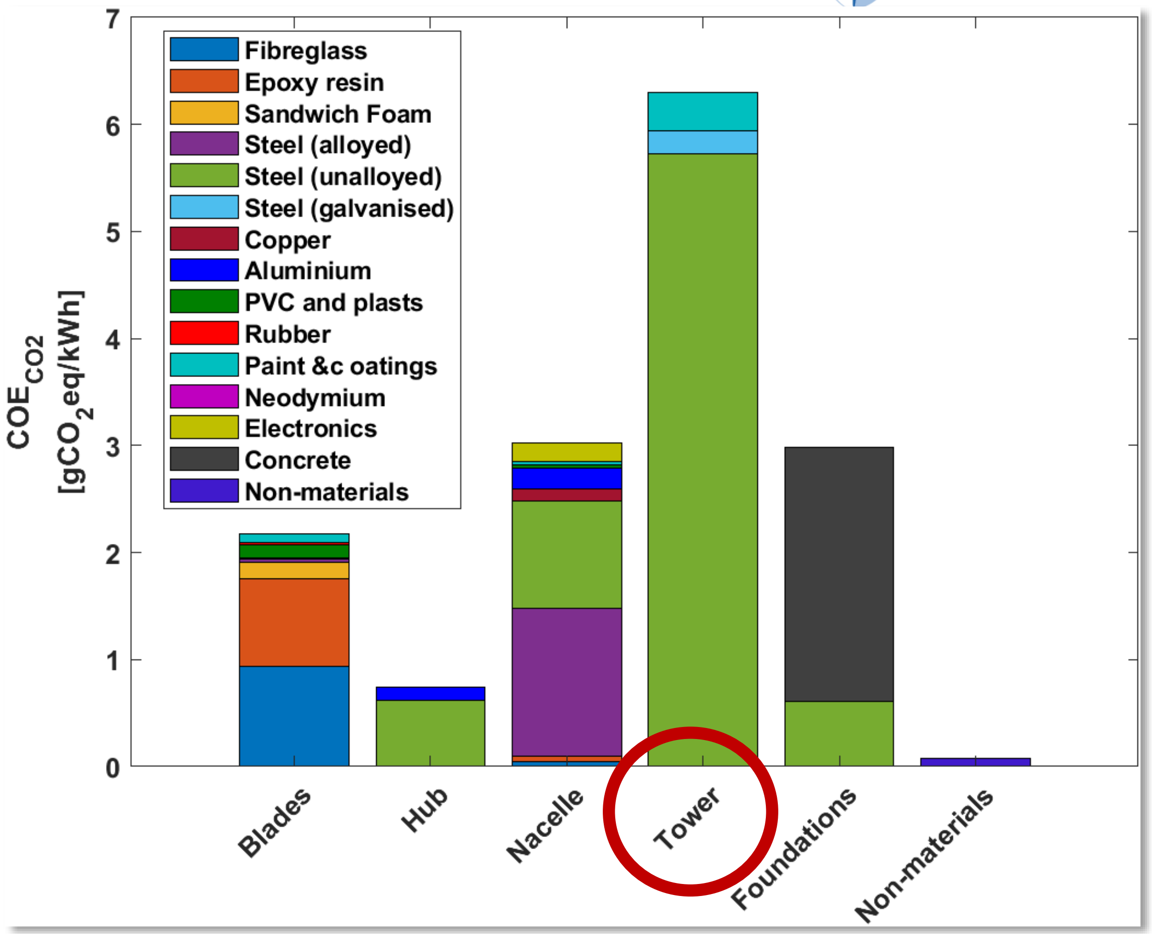
1. Goal & scope definition
2. Inventory analysis
3. LCA impact assessment
4. Interpretation

Source: *The International Reference Life Cycle Data System (ILCD) Handbook*. JRC reference report, 2012, EUR 24982 EN

LCA design at TU-Munich:

Pictures: IB Sing (onshore), WindEurope (offshore), Kitekraft GmbH (airborne)

LCA design at TU-Munich:



- **Onshore wind turbine**
- IEA Task 37 3.35MW ref. turbine
- **COE_{CO2}** ~15.29 gCO2eq/kWh

Guilloré, A., Canet, H., and Bottasso, C. L.: *Life-Cycle Environmental Impact of Wind Turbines: What are the Possible Improvement Pathways?,* J. Phys.: Conf. Ser., 2265, TS13, 2022

Canet, H., Guilloré, A., and Bottasso, C. L.: *The eco-conscious wind turbine: design beyond purely economic metrics*, Wind Energ. Sci., 2022.

Pictures: IB Sing (onshore), WindEurope (offshore), Kitekraft GmbH (airborne)

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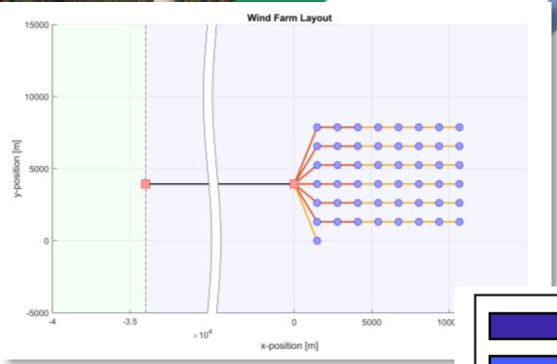
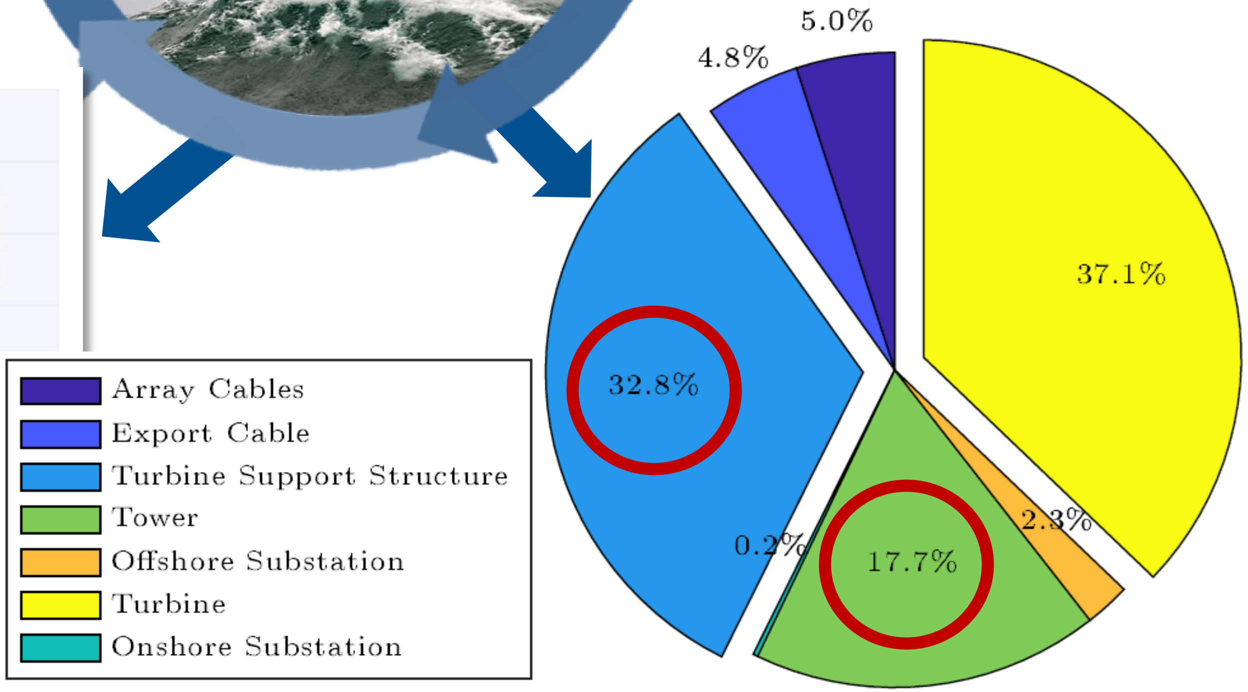


- **Offshore wind farm**
- Horns Rev 3 wind farm
- **COE_{CO2}** ~13.1 gCO2eq/kWh



Publication(s) to come !

Samuel Kainz, Adrien Guilloré, Carlo L. Bottasso, Helena Canet

Pictures: IB Sing (onshore), WindEurope (offshore), Kitekraft GmbH (airborne)

LCA design at TU-Munich:

Airborne wind energy !

Pictures: IB Sing (onshore), WindEurope (offshore), Kitekraft GmbH (airborne)

AWES Kitekraft

Kitekraft:

- Based in Munich
- Founded in 2019

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Flying wind turbines.

Picture: Kitekraft GmbH

Kitekraft technology: Fly-gen. rigid drag power kite

Kite

- Airframe: wings, beams, foam beams, bracings
- Tail
- Powertrain: motors/generators, rotors
- Fuselage: electronics
- Gimbal

Tether

- Aramid core rope
- Electric cables
- Communication
- Protection

Ground station

- Base tower
- Winch
- Perch
- Drive train: motors
- Safety
- Electronics and communication
- Power electronics: batteries, grid inverter
- Gimbal

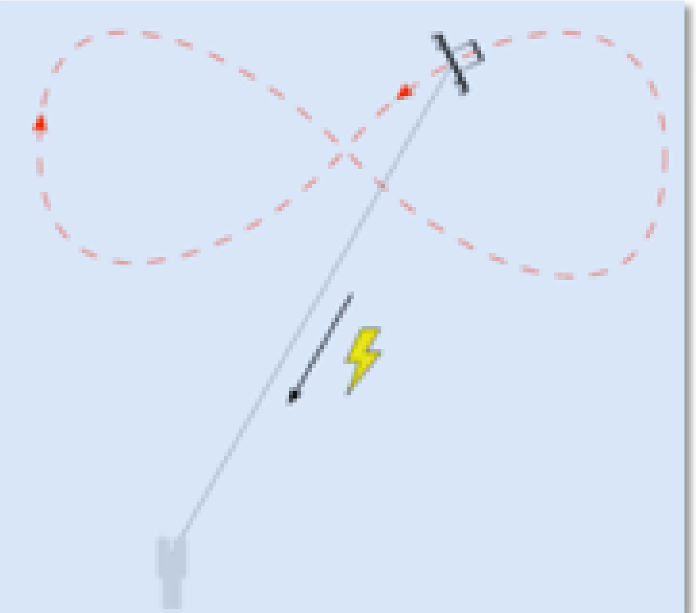
KITE//KRAFT
Flying wind turbines.

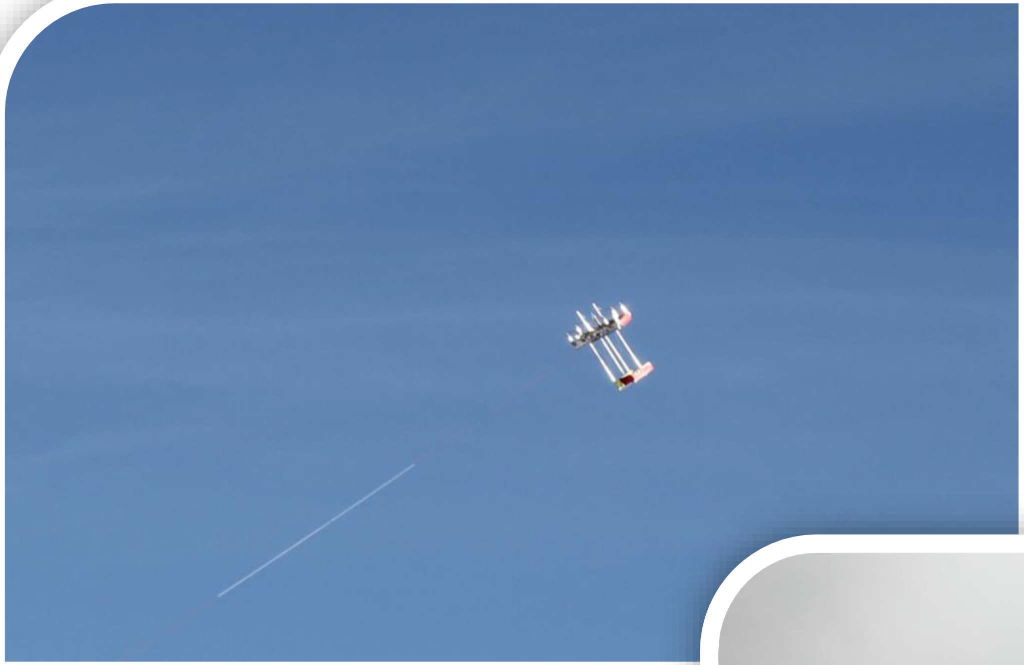
Picture: Kitekraft GmbH

Kitekraft GmbH: Figure eight flight

Operation stages

1. Resting position
2. Take-off
3. Transition into figure eight flight
4. **Figure eight flight**
5. Transition out of figure eight flight
6. Hover down
7. Landing





Successfull flight tests !

In various wind conditions

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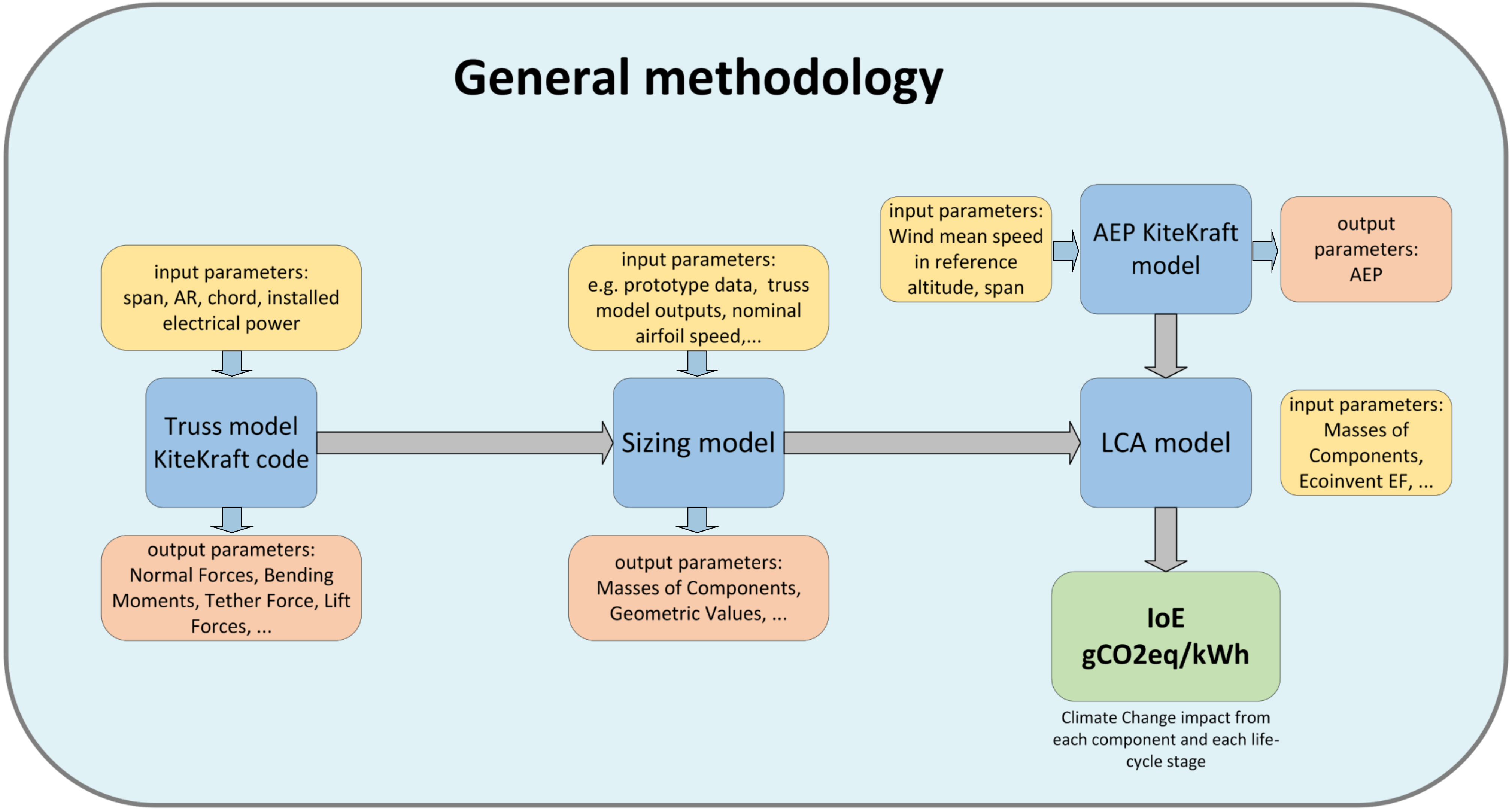
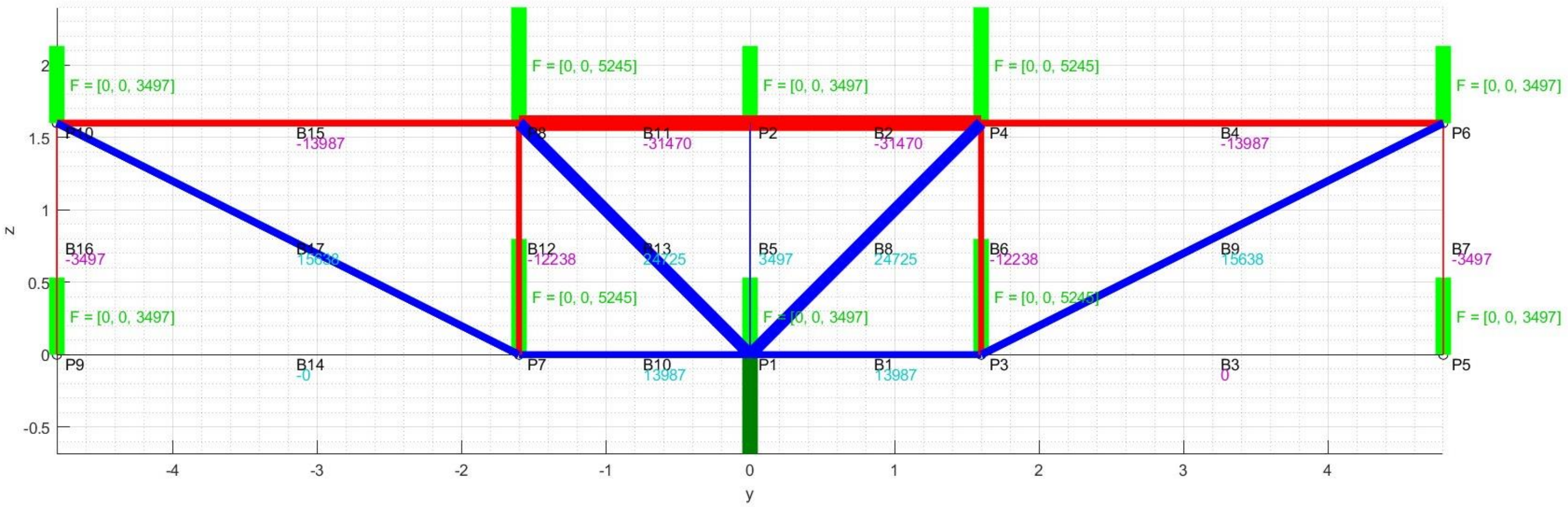
Sizing model and LCA implementation

Design tool with LCA:



Truss model: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-13987
B11
-31470
P2
B2
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P4
B4
-13987
P6
B16
-3497
B17
B12
-12238
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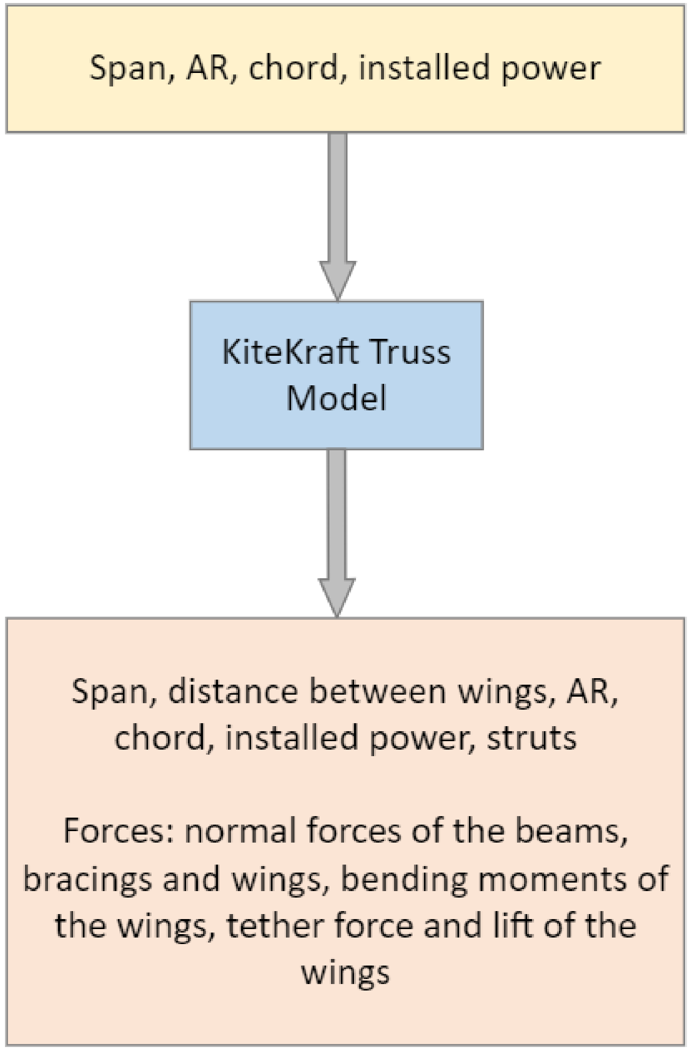
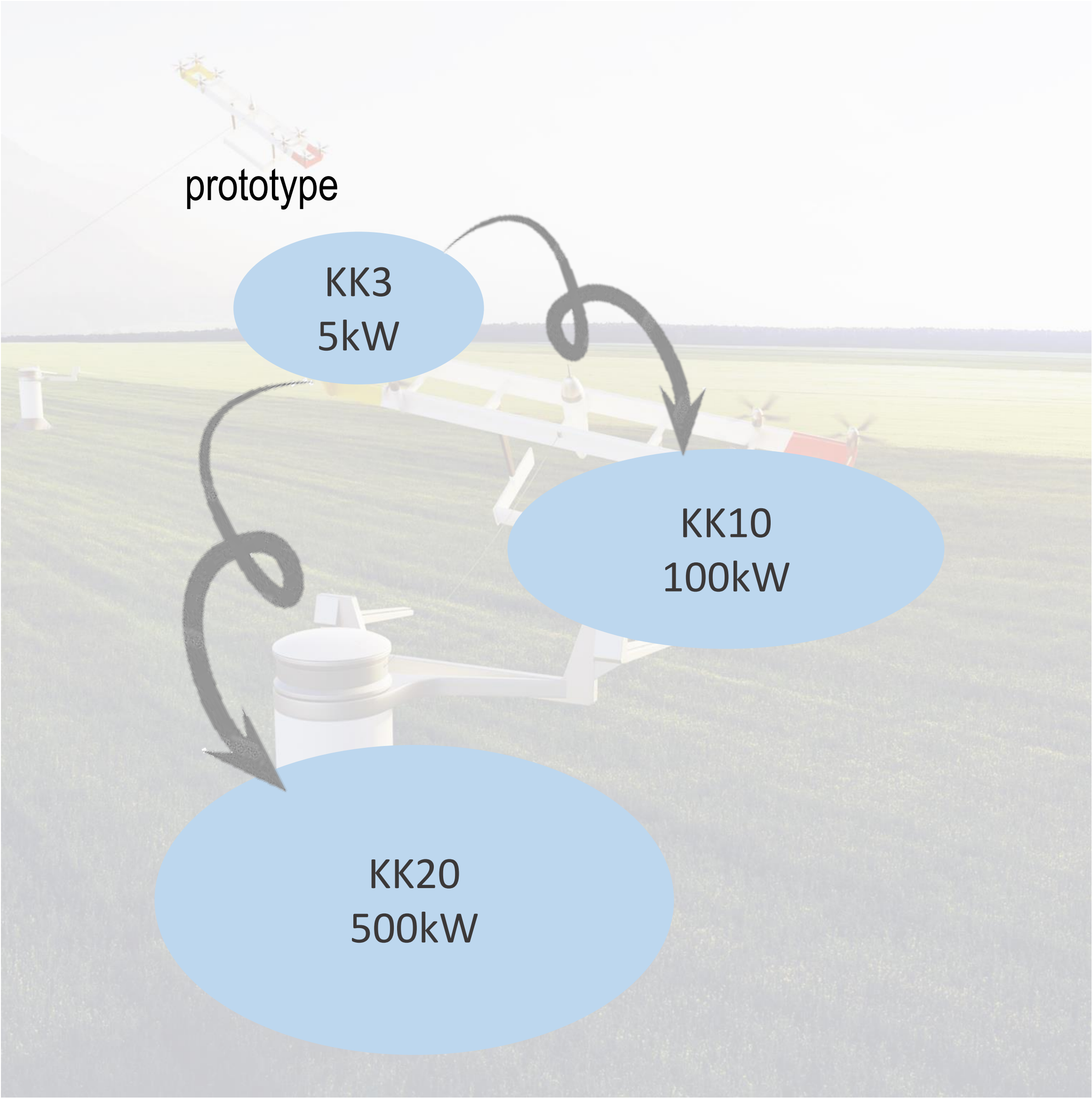

Span, AR, chord, installed power
KiteKraft Truss Model
Span, distance between wings, AR, chord, installed power, struts
Forces: normal forces of the beams, bracings and wings, bending moments of the wings, tether force and lift of the wings

Sizing model:



Truss Model inputs
Flexible design variables (i.e. power ratio)
Environmental fixed variables
Kite parameters (i.e. geometric parameters)
Inputs from providers (i.e. beam dimensions)
Rotor parameters (i.e. number of rotors)
Tether parameters (i.e. characteristics of the materials)
Powertrain parameters (i.e. specific mass of electrical machines)
KK3 model input data: (characteristics of the KK3 model)

↓

Sizing model

↓

Mass of each component and geometric and characteristic parameters

Picture: Kitekraft GmbH

LCA model:

Impact category: Global Warming Potential (GWP)

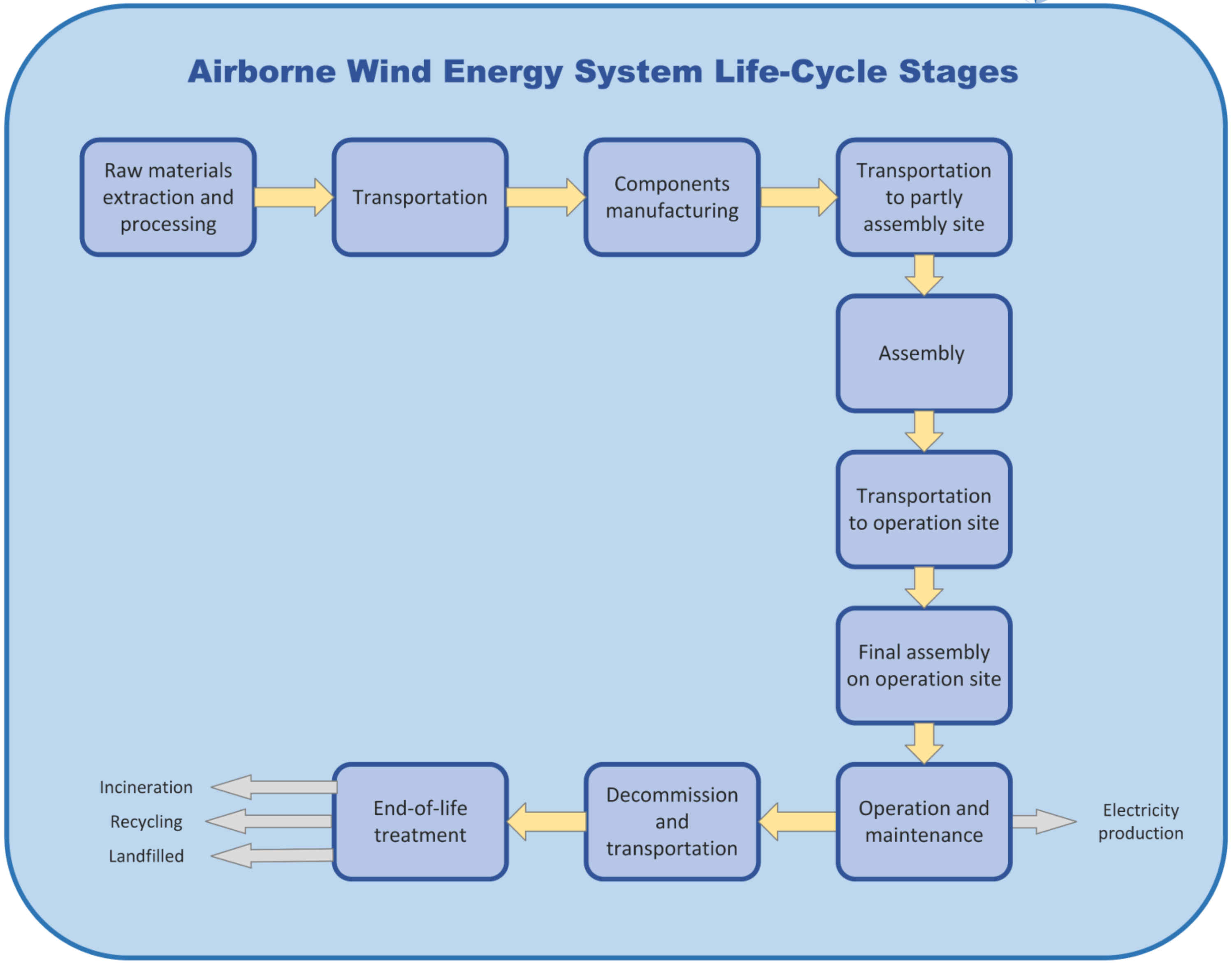
Functional unit: 1 kWh of electricity produced by the system and ready to be delivered to the energy grid.

System scope definition:

- One kite Kitekraft GmbH, of any size
- Lifetime: 20 years
- Emplacement: Brandenburg, Germany
- Connection to the grid not considered.

EOL method: Open-loop

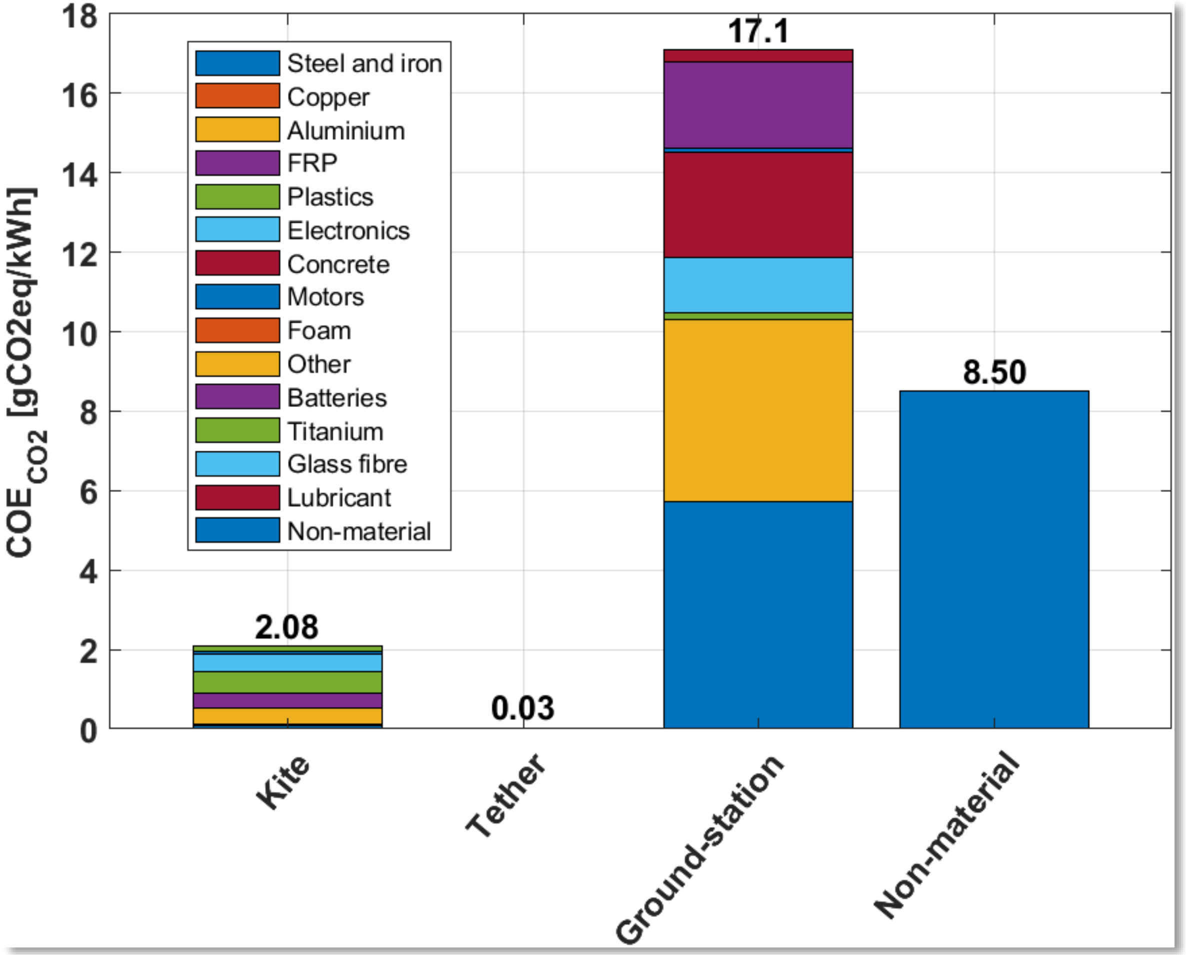
Main data
2021



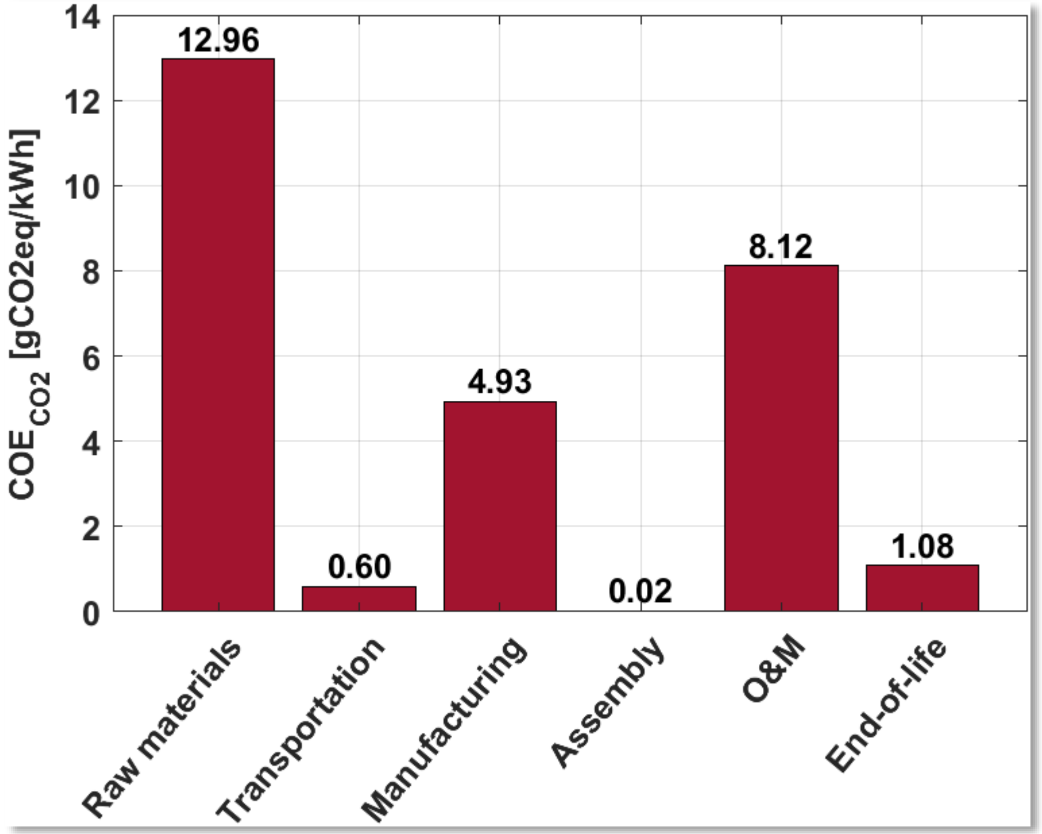
LCA Results

Environmental impact estimations:

KK3 5kW Kite: COE_{CO2} ~28.02 gCO2eq/kWh



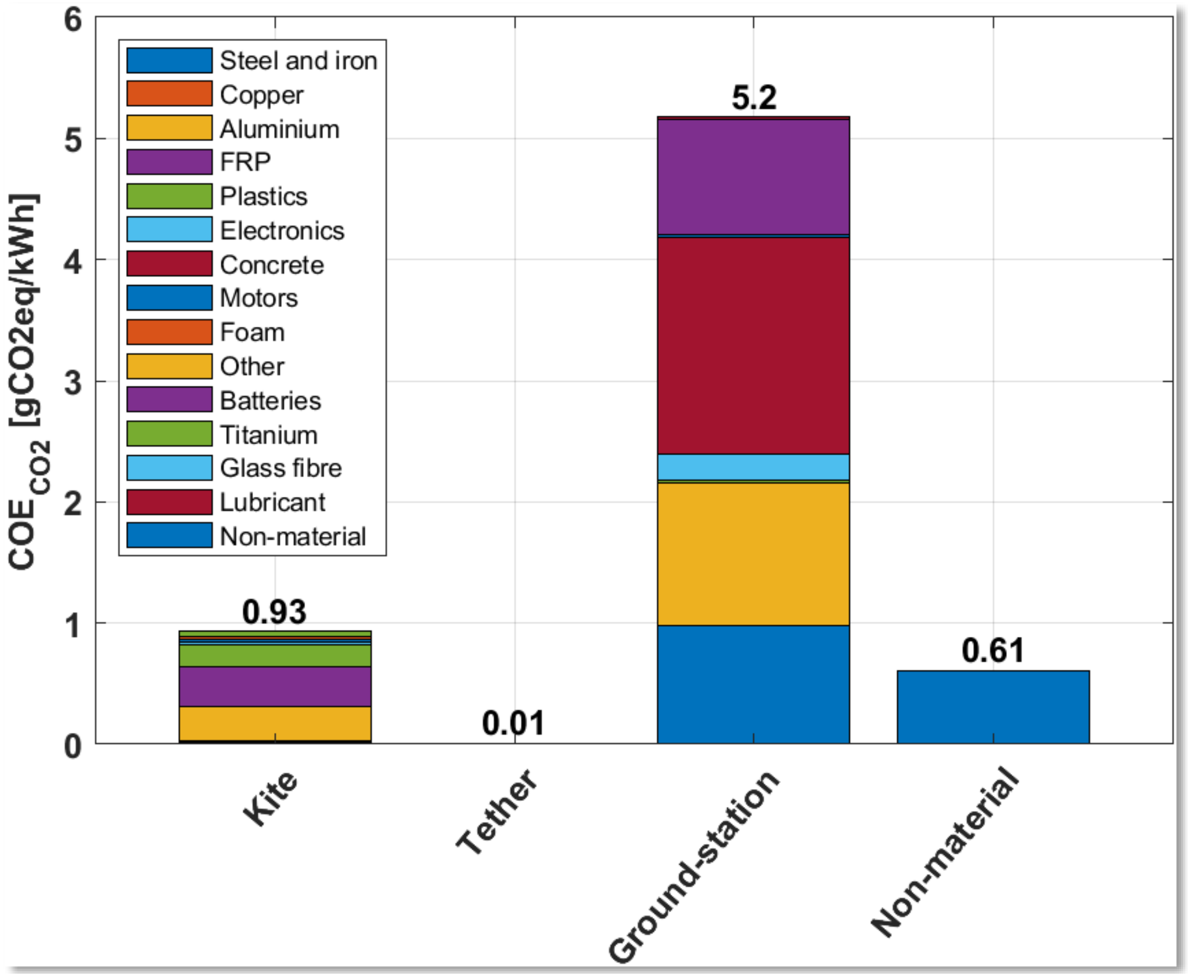
Components



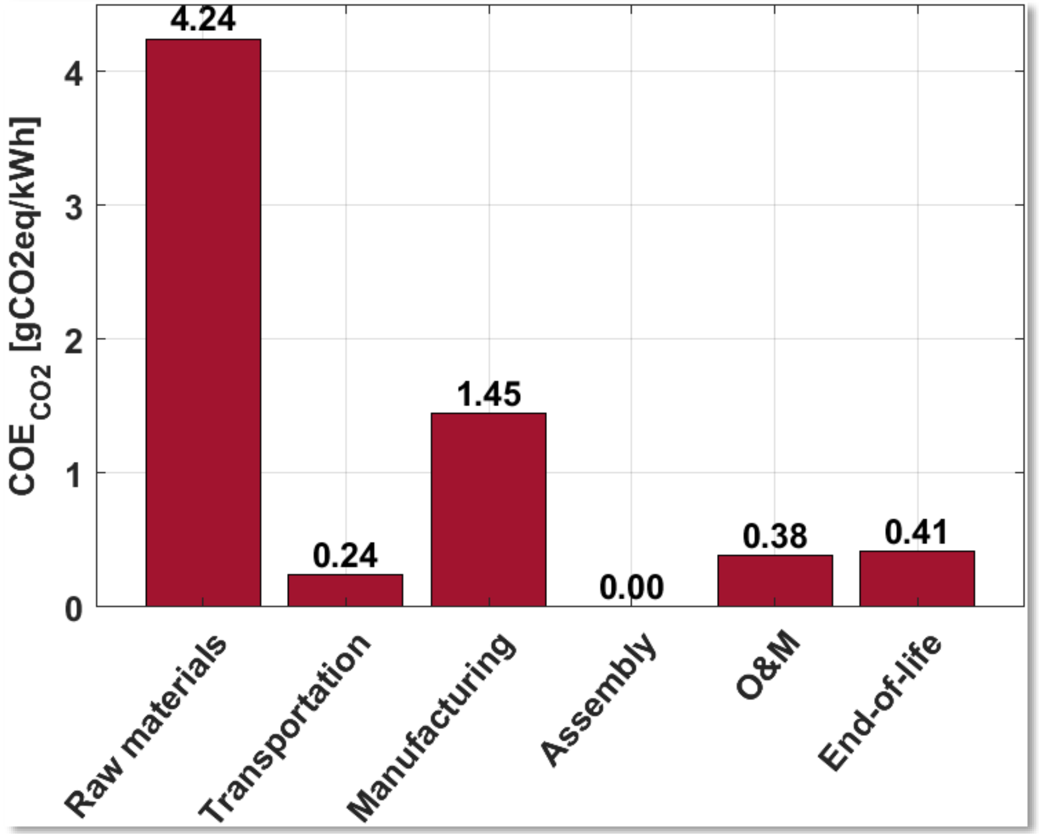
Life-stages

Environmental impact estimations:

KK10 100kW Kite: COE_{CO2} ~6.72 gCO2eq/kWh



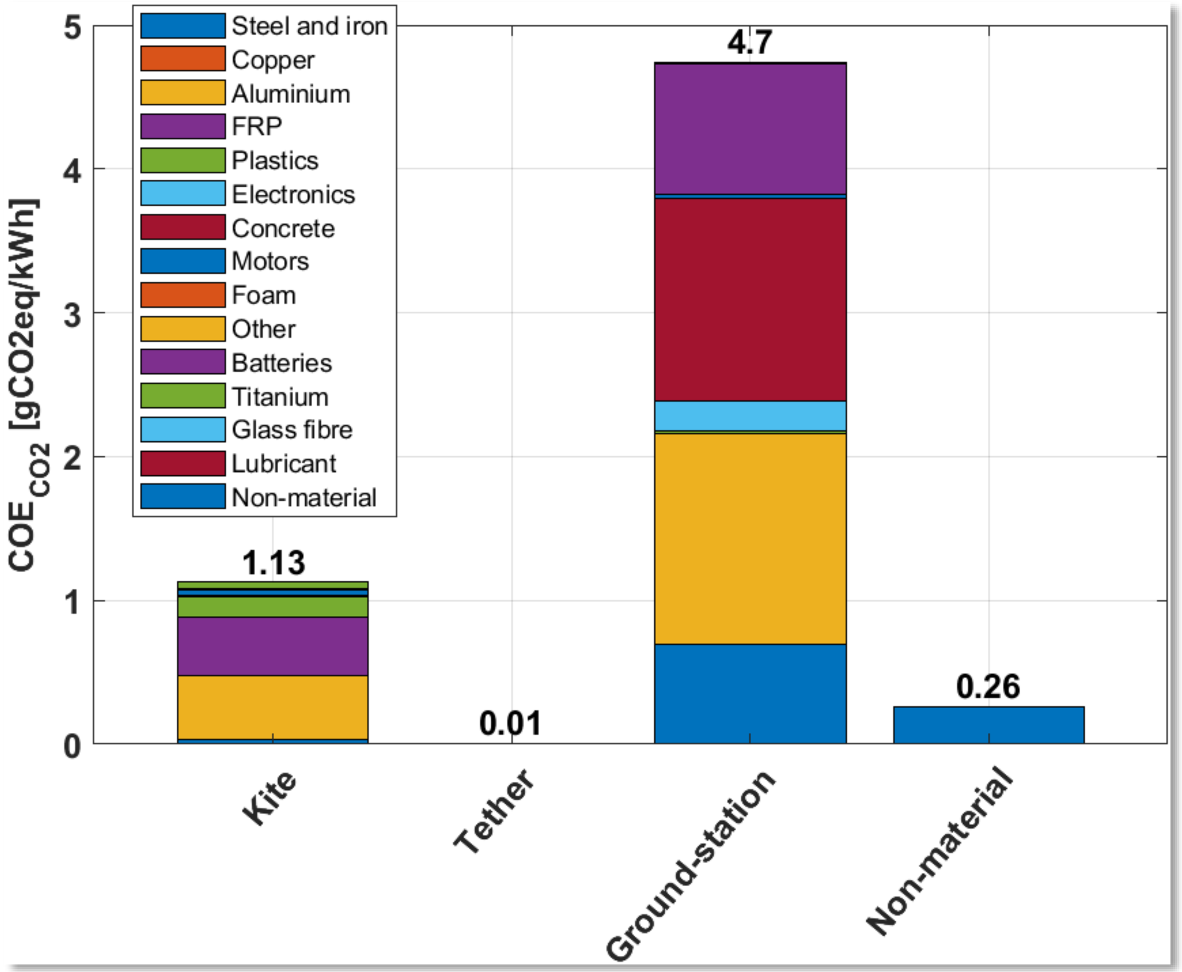
Components



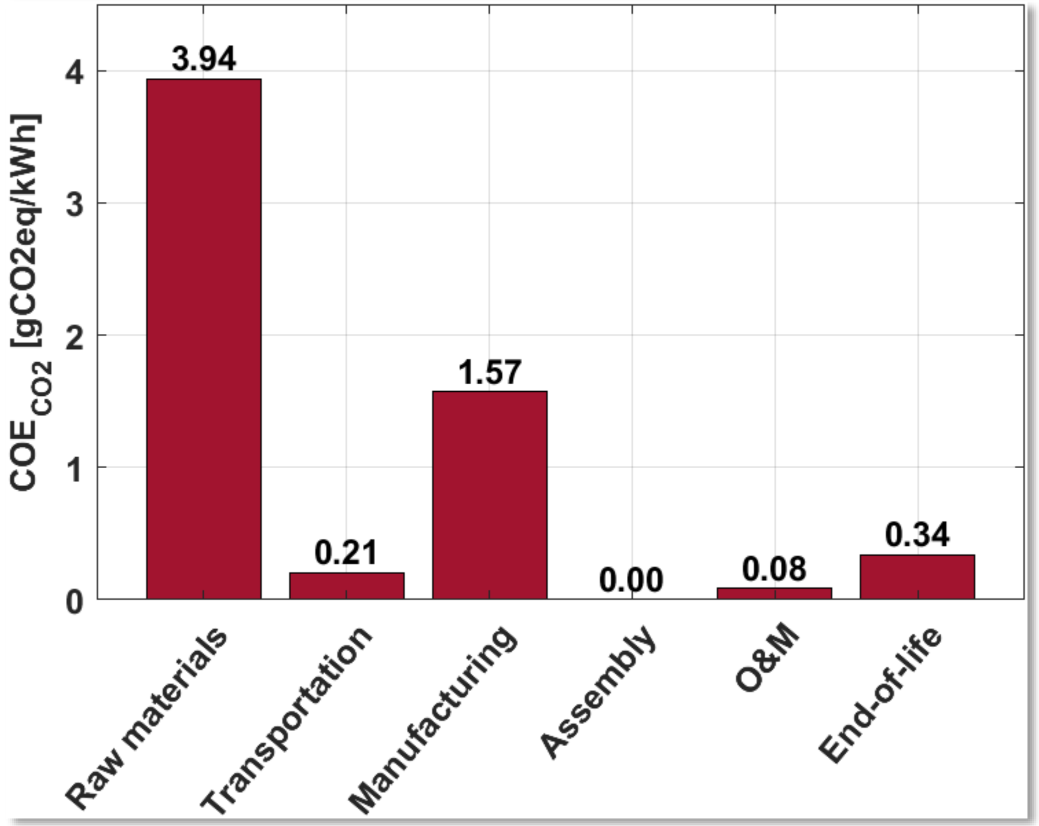
Life-stages

Environmental impact estimations:

KK20 500kW Kite: COE_{CO2} ~5.95 gCO2eq/kWh

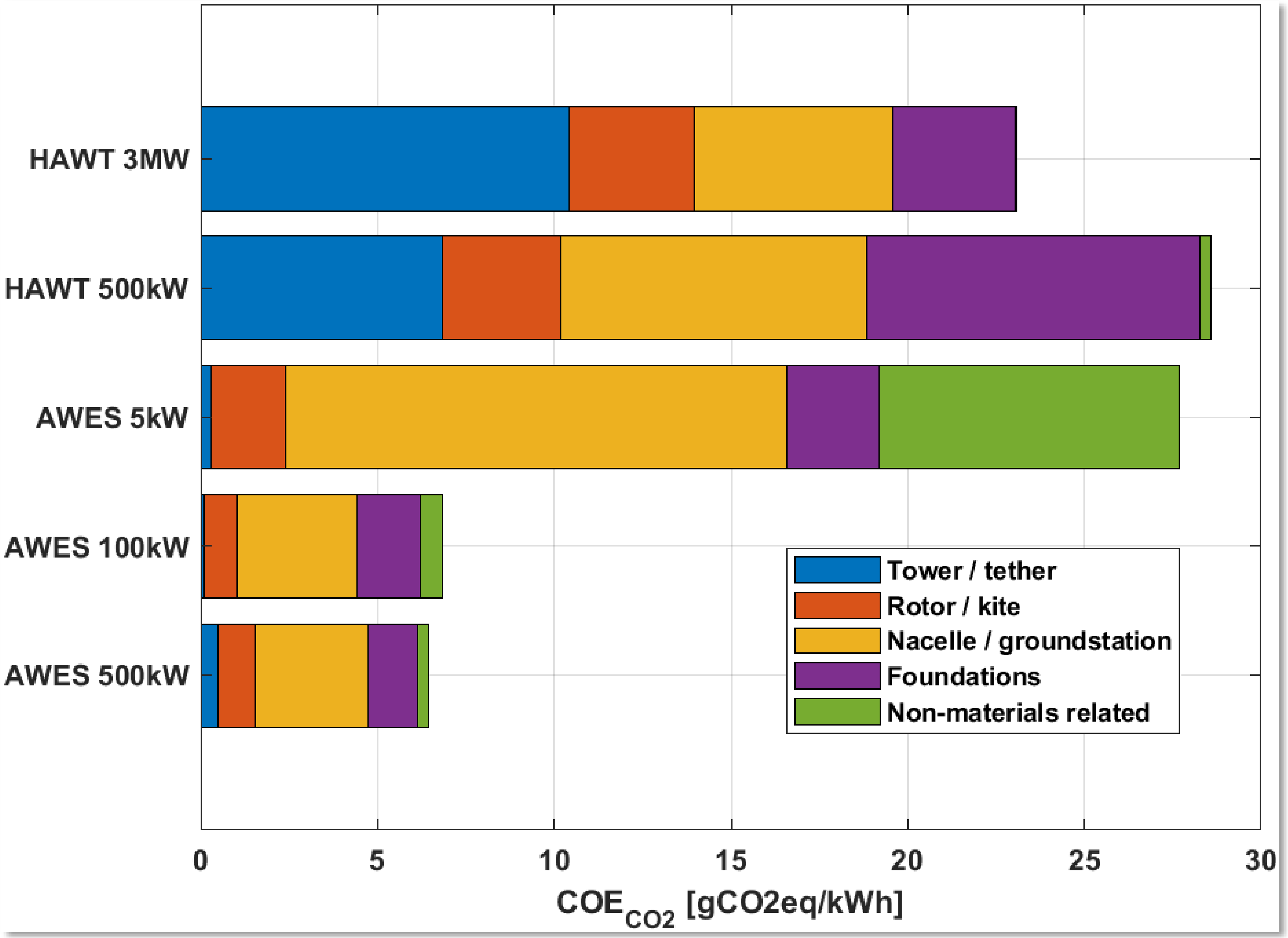


Components



Life-stages

Comparison: all using TUM LCA design tool



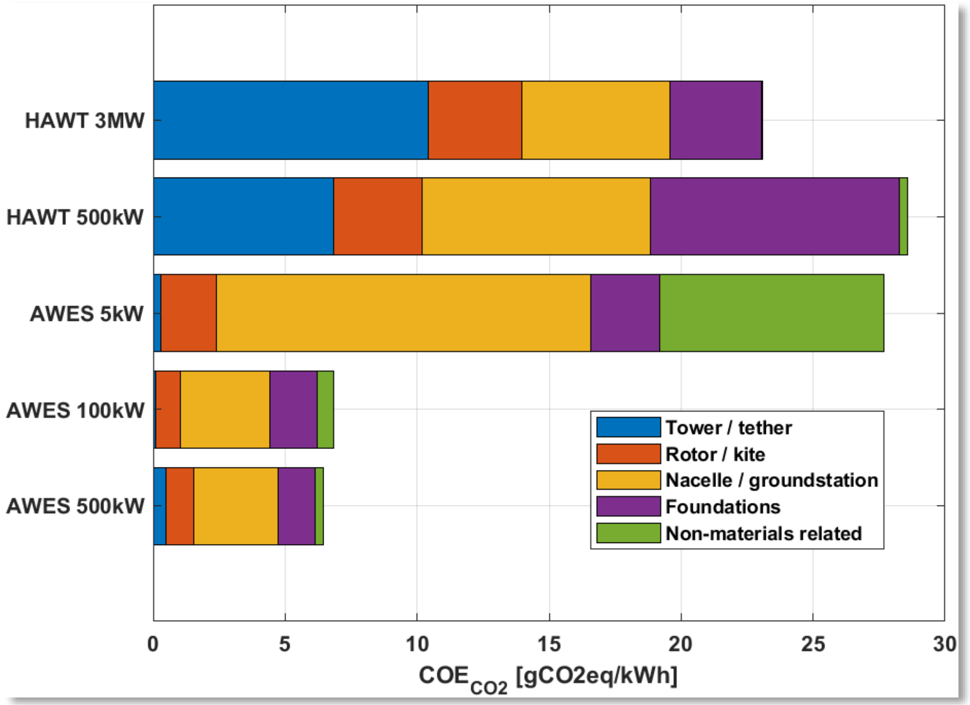
Pictures: IB Sing (onshore), Kitekraft GmbH (airborne)

Conclusions & Future Work

Key take-aways
LCA for AWES



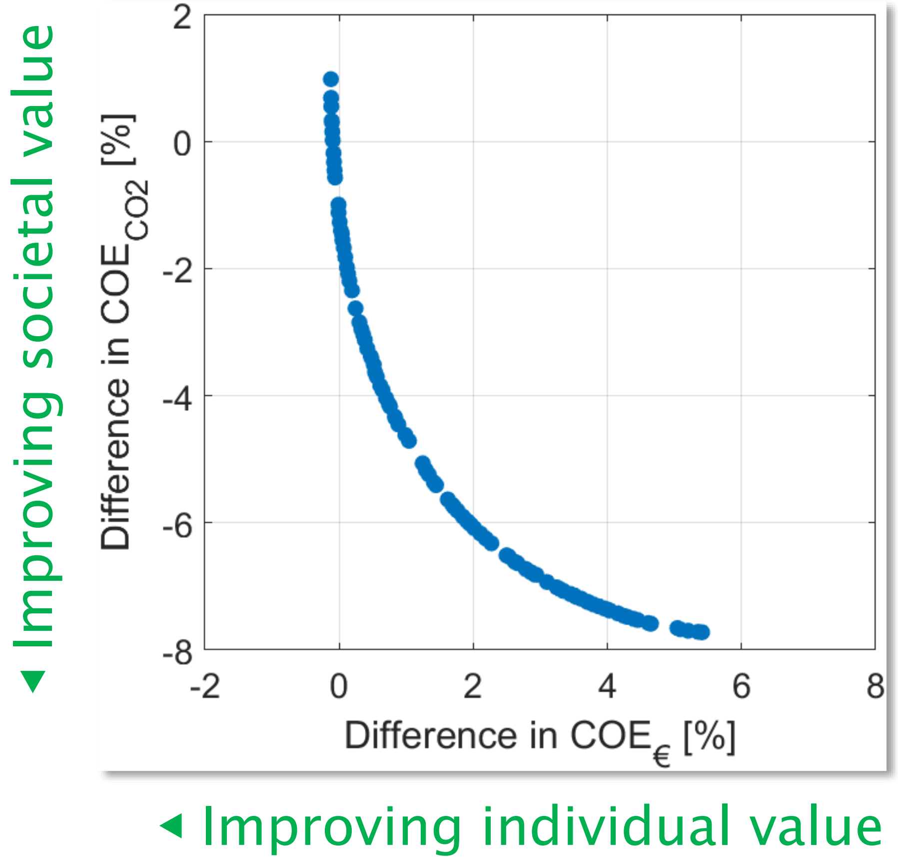
- LCA results for 3 Kitekraft models (KK3, KK10, KK20), by components, materials and life-stages
- **Low COE_{CO2}**, as some other LCA studies on Airborne wind (<10 gCO2eq/kWh)
- Groundstation (concrete, batteries,…) is the main remaining environmental impact
- **Benefits of upscaling !**



Pictures: IB Sing (onshore), WindEurope (offshore), Kitekraft GmbH (airborne)

Future work…

- Improve **mass sizing model** for upscaling the Kite prototype
- Eco-conscious design ***optimization*** of Airborne Wind Energy Systems (drag power kite) using Life Cycle Assessment
- Farm-level for Airborne Wind
- Value-based design (market value and displaced CO2 emissions)…



Picture: Kitekraft GmbH

Thank you for your attention!

Any questions?

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