# Sustainability Assessment of NET fuel production processes

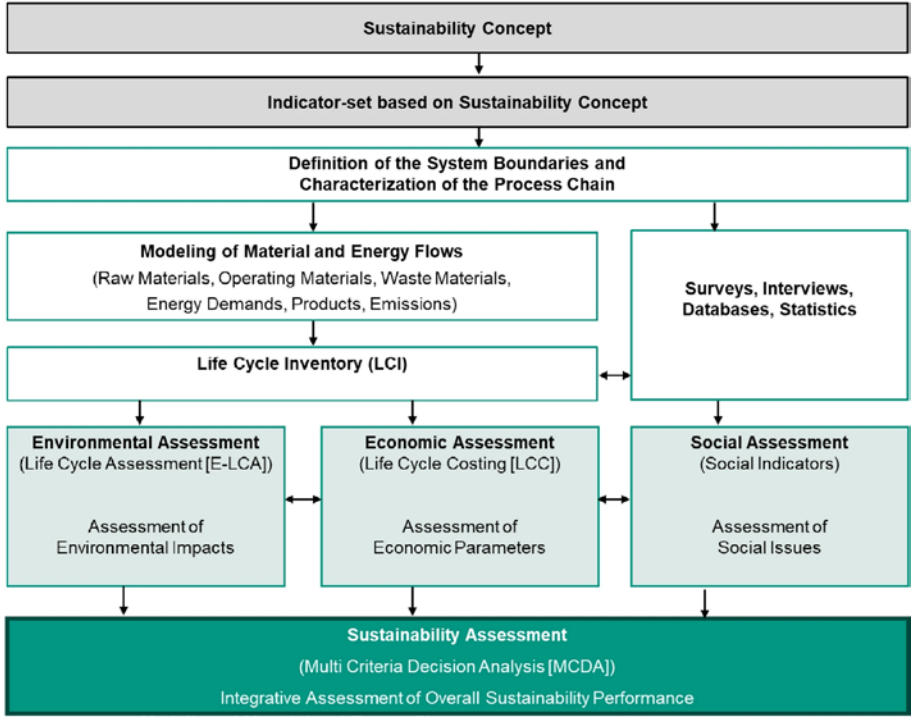
Martina Haase, Manuel Andresh, Andreas Patyk, Christine Rösch

**Workshop NET@KIT, 23. März 2023**

# Agenda

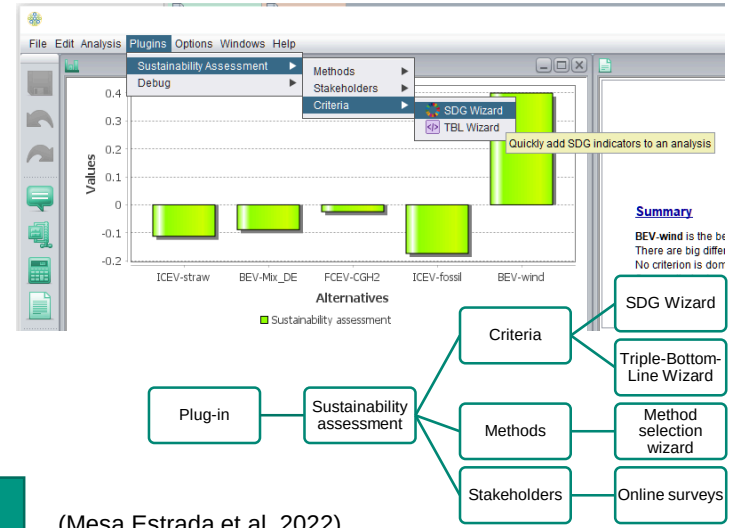
- Approach for Sustainability Assessment
- Fuel Production Processes (Examples from the reFuels project)
- Results
  - Life Cycle Impact Assessment
  - MCDA for Sustainablity Assessment
- Takeaways

# Approach for Sustainability Assessment




(Haase et al. 2022a, 2022b)

- Decision Support Tool for MCDA assisted sustainability assessment




(Mesa Estrada et al. 2022)

*KIT MCDA Tool (https://portal.iket.kit.edu/projects/MCDA/)*

# Approach for Sustainability Assessment

## MCDA for Sustainability Assessment

- Multi Criteria Decision Analysis (MCDA) to support decision-making processes
- Comparison of alternatives based on relevant, often conflicting, criteria.
  - Mathematical procedures to aggregate results from sub-problems
  - Systematically determine the best choice for a decision maker
  - Selection and weighting of criteria as key aspects

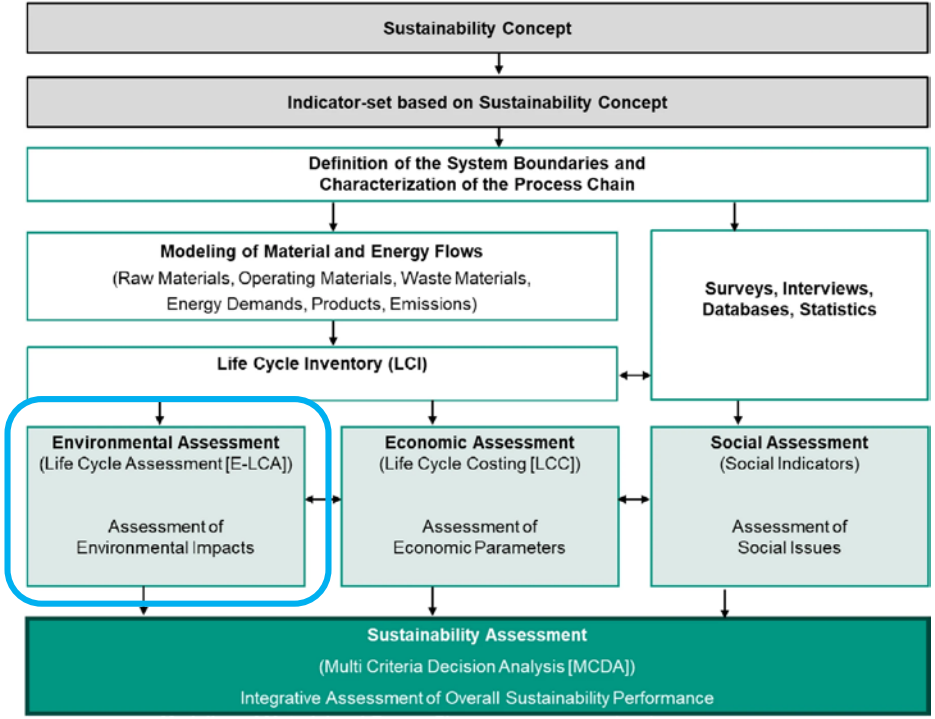
*Common MCDA methods for criteria aggregation*

| Method | Description | Pros | Cons |
|---|---|---|---|
| WSM* | Simple linear additive models | simple computation, transparent | only basic estimations, -only single preference |
| TOPSIS** | best alternative should have the shortest (Euclidian) distance from the positive ideal solution while it has the longest distance from the negative ideal solution | simple computation | does not consider difference between neg. & pos. values |
| PROMETHEE*** | construction of outranking relation to compare each pair of actions; | considers interdependency of criteria | complex method, computation efforts high |

(Guitouni and Martel 1998, Wang et al. 2009)

* Weighted Sum Method ** Technique for Order Preference by Similarity to Ideal Solution *** Preference ranking organization method for enrichment evaluation

# Approach for Sustainability Assessment

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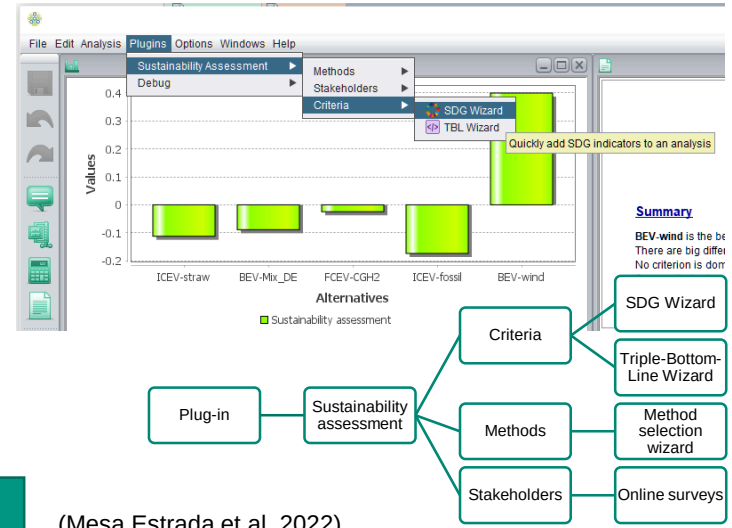


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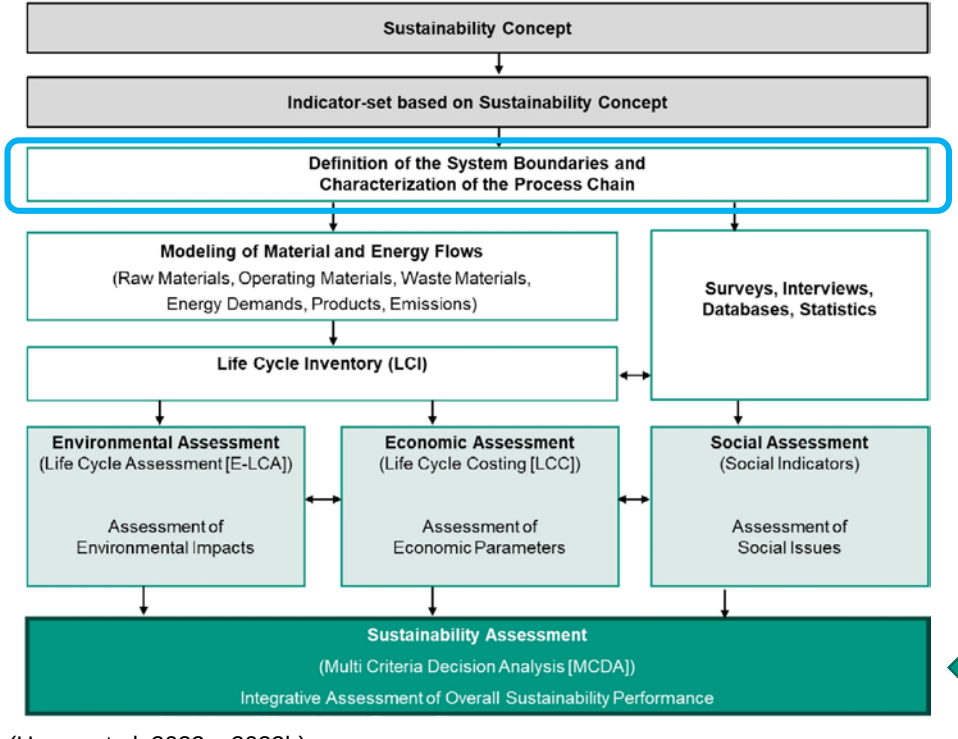
# Life Cycle Assessment of fuel production pathways

## Examples from the reFuels project

- Comparison of potential environmental impacts of different fuel production pathways
  - Analysis of the effects of different process constellations and locations
  - Identification of hotspots and potentials
  - Focus on Global Warming Potential (GWP), Fine Particulate Matter Formation, Fossil Resource Scarcity

- Fuel production pathways
  - Microstructured Fischer-Tropsch (FT) synthesis with $CO_2$ from Direct Air Capture (DAC)
  - Conventional Fischer-Tropsch (FT) synthesis with $CO_2$ from a cement plant
  - Bioliq Dimethyl Ether (DME) fuel synthesis with $CO_2$ capture by biomass

# Approach for Sustainability Assessment

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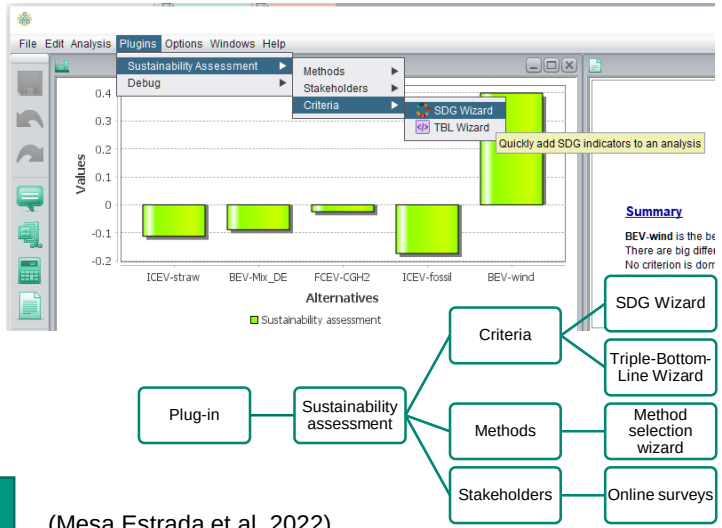


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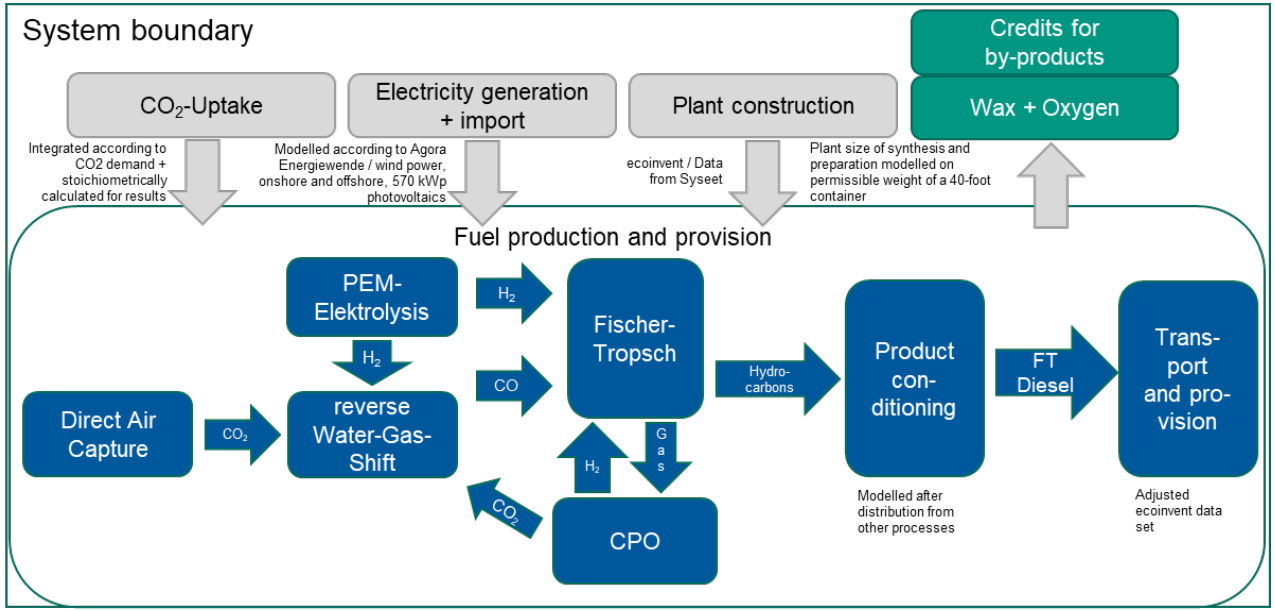
# Fuel production processes

## Examples from the reFuels project

- Microstructured Fischer-Tropsch (FT) synthesis



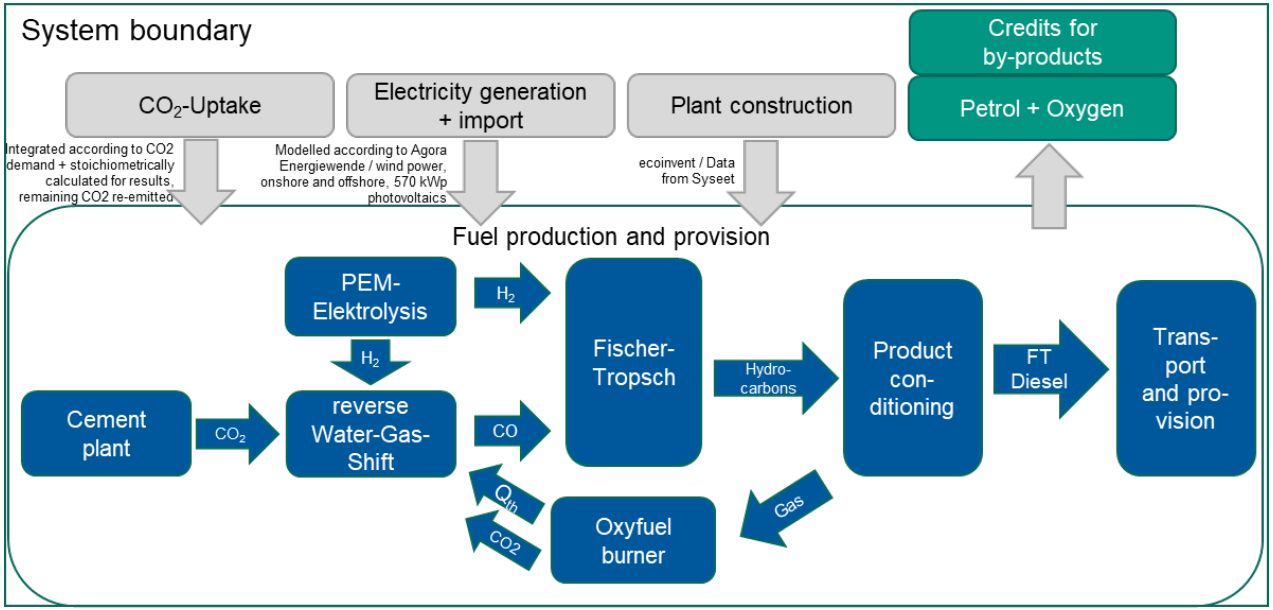

(Andresh et al. 2021)

Process data from Vázquez et al. (2018)

# Fuel production processes

## Examples from the reFuels project

- Conventional Fischer-Tropsch (FT) synthesis



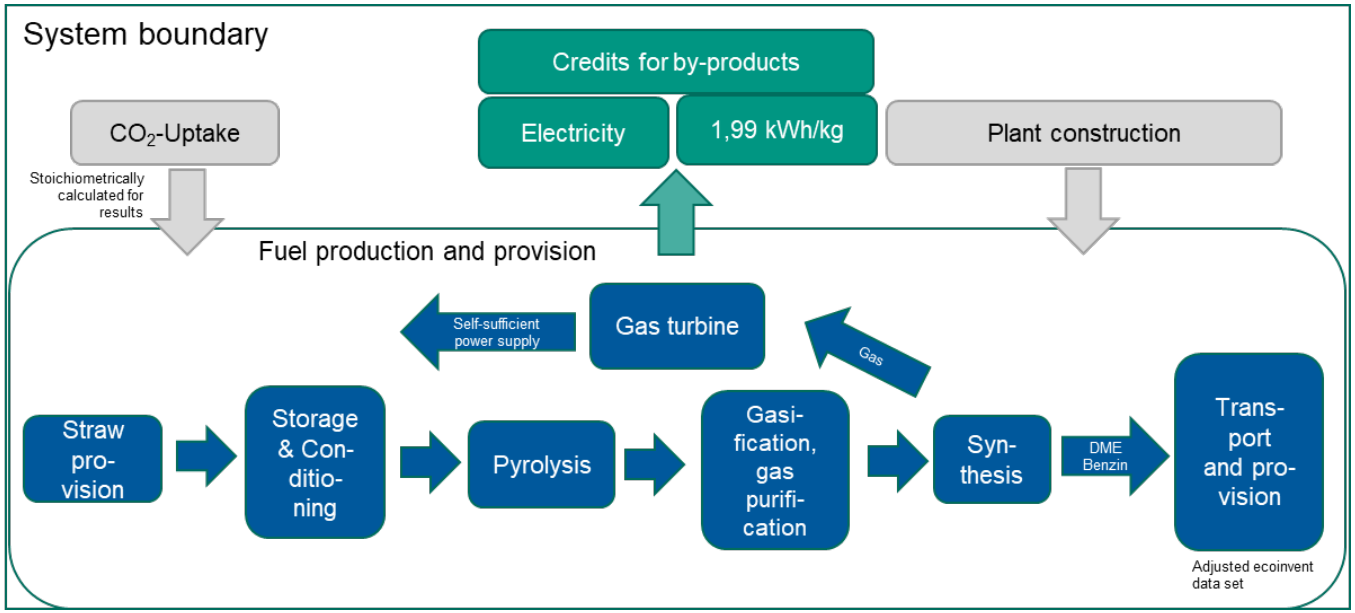

(Andresh et al. 2021)

Process data from Institute for Industrial Production (KIT-IIP)

# Fuel production processes

## Examples from the reFuels project

- Bioliq DME petrol synthesis

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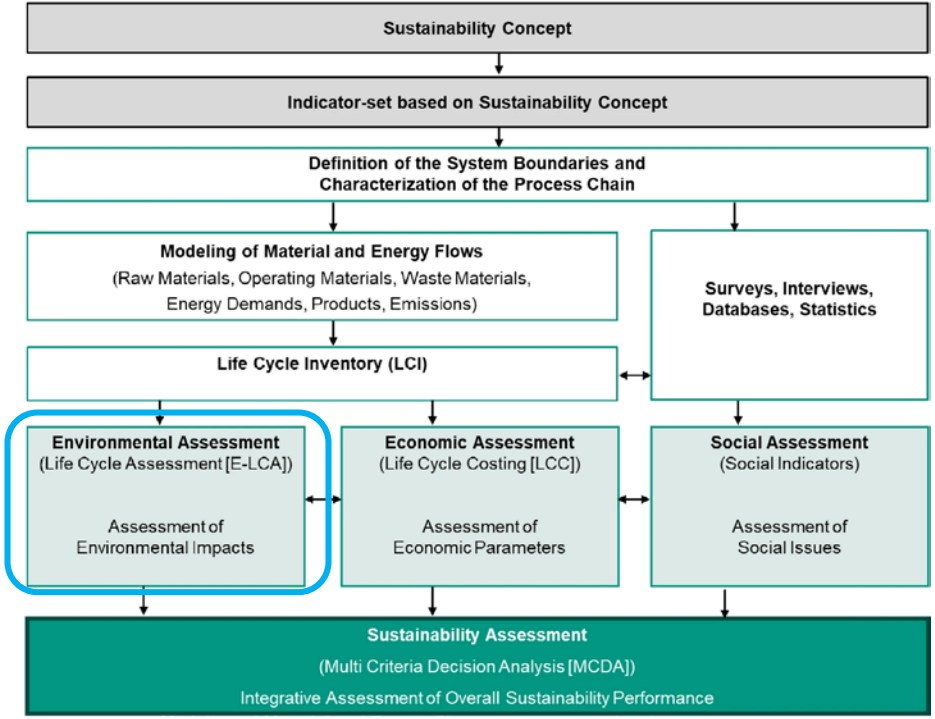
Process data from Trippe (2013): Techno-ökonomische Bewertung alternativer Verfahrenskonfigurationen zur Herstellung von Biomass-to-Liquid (BtL) Kraftstoffen und Chemikalien

# Approach for Sustainability Assessment

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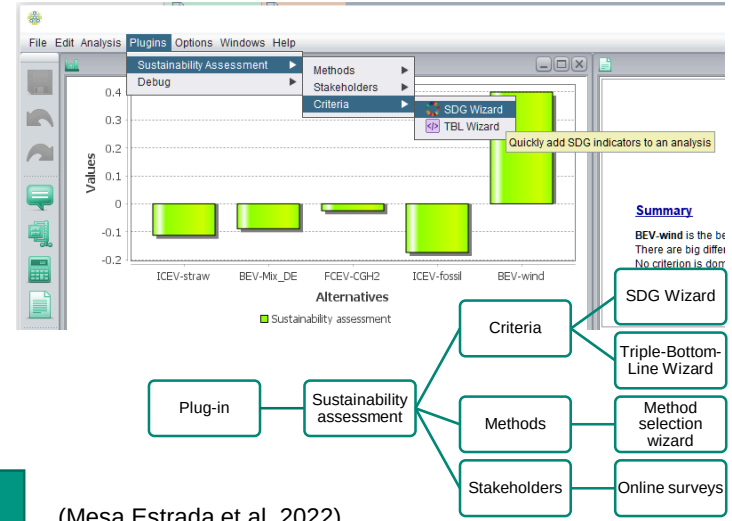


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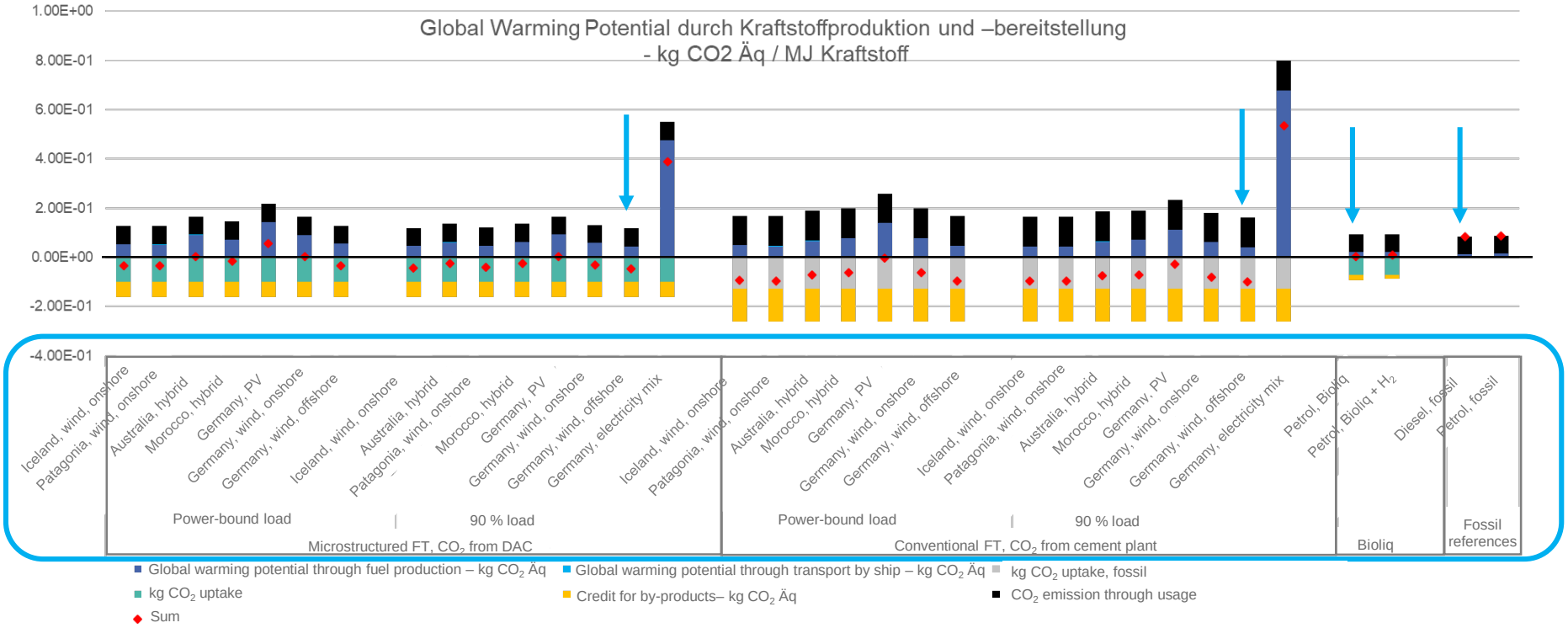
# Life Cycle Impact Assessment

## Global Warming Potential of considered alternatives




(Andresh et al. 2021)

# Life Cycle Impact Assessment

## ReCiPe 2016 Midpoint

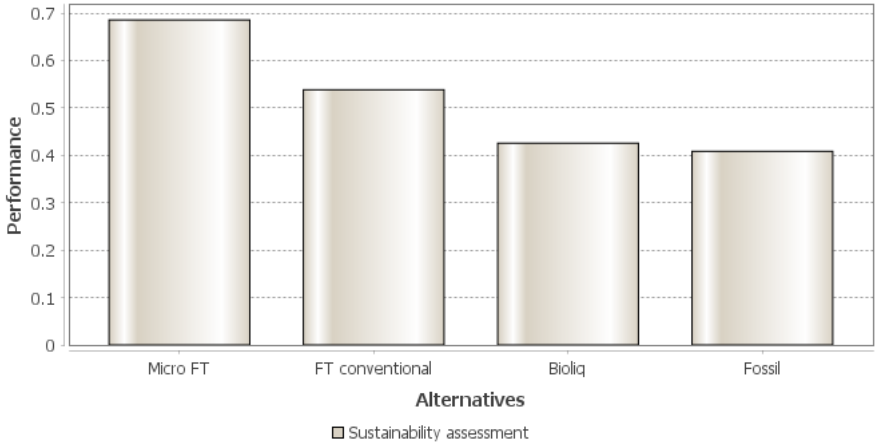
| Impact categories ReCiPe 2016 Midpoint | Unit | Microstructured FT, $CO_2$ from DAC | Conventional FT, $CO_2$ from cement plant | Bioliq, $CO_2$ capture by biomass | Fossil (Diesel) | ... |
|---|---|---|---|---|---|---|
| | | 90% load | | | | |
| | | Germany, wind, offshore | Germany, wind, offshore | Straw, regional | | |
| Fine particulate matter formation | kg PM2,5 eq | -4.0E-05 | -3.2E-05 | 4.4E-05 | 3.6E-05 | ... |
| Fossil resource scarcity | kg oil eq | -1.2E-02 | -2.5E-02 | 1.7E-03 | 2.9E-02 | ... |
| Freshwater ecotoxicity | kg 1,4-DCB | 2.2E-02 | 3.7E-02 | 7.3E-04 | 1.1E-04 | ... |
| Freshwater eutrophication | kg P eq | -4.6E-05 | -2.5E-05 | -1.1E-05 | 7.3E-07 | ... |
| Global warming | kg CO2 eq | -2.0E-02 | -7.4E-02 | 2.0E-03 | 8.6E-02 | ... |
| Human carcinogenic toxicity | kg 1,4-DCB | 1.5E-02 | 2.3E-02 | 5.5E-04 | 5.7E-04 | ... |
| Human non-carcinogenic toxicity | kg 1,4-DCB | 4.0E-02 | 1.2E-01 | 4.2E-02 | 2.6E-03 | ... |
| Ionizing radiation | kBq Co-60 eq | -3.0E-02 | -2.5E-02 | -2.4E-03 | 7.6E-04 | ... |
| Land use | m2a crop eq | -6.7E-04 | 5.6E-04 | 1.7E-04 | 1.1E-04 | ... |
| Marine ecotoxicity | kg 1,4-DCB | 2.7E-02 | 4.5E-02 | 1.1E-03 | 2.1E-04 | ... |
| Marine eutrophication | kg N eq | -2.8E-06 | -7.9E-07 | -8.7E-07 | 1.1E-07 | ... |
| Mineral resource scarcity | kg Cu eq | 7.3E-04 | 1.1E-03 | 2.4E-04 | 1.7E-05 | ... |
| Ozone formation, Human health | kg NOx eq | -4.3E-05 | -3.1E-05 | 9.9E-05 | 5.0E-05 | ... |
| Ozone formation, Terrestrial ecosystems | kg NOx eq | -4.2E-05 | -3.1E-05 | 1.0E-04 | 5.3E-05 | ... |
| Stratospheric ozone depletion | kg CFC11 eq | 3.1E-07 | -2.3E-08 | 8.0E-09 | 2.3E-08 | ... |
| Terrestrial acidification | kg SO2 eq | -1.1E-04 | -1.2E-04 | 8.6E-05 | 1.1E-04 | ... |
| Terrestrial ecotoxicity | kg 1,4-DCB | 1.1E-01 | 1.9E-01 | 1.5E-01 | 4.2E-02 | ... |
| Water consumption | m3 | -2.6E-03 | -1.2E-05 | 1.4E-04 | 9.9E-06 | ... |

(Andresh et al. 2021)

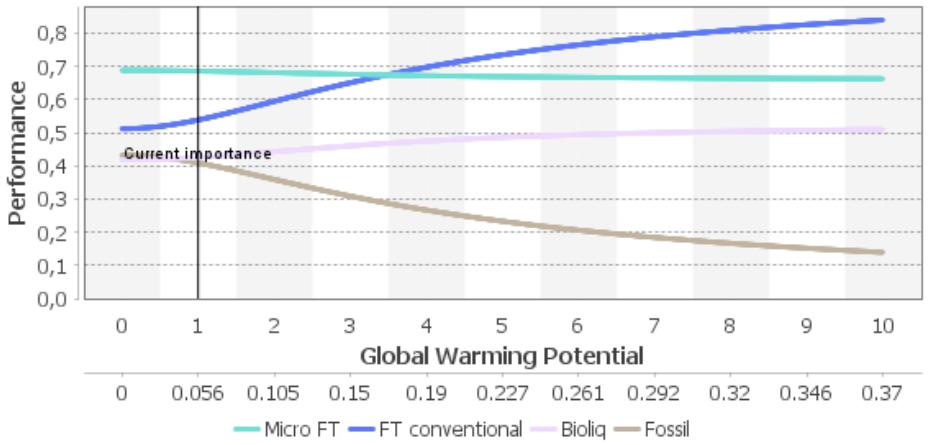
# MCDA for Sustainability Assessment

## Exemplary results – TOPSIS*

- Equal weighting of criteria




- Stability of weights – GWP




*Technique for Order Preference by Similarity to ideal Solution

*KIT MCDA Tool (https://portal.iket.kit.edu/projects/MCDA/)*

# Takeaways

- Presented fuel production processes show negative $CO_2$ equivalents considering production and use of primary and by-products
- For sustainability assessment, economic, social and further environmental impacts need to be considered
- MCDA for integrative consideration of criteria
- Selection and weighting of criteria has a decisive influence on results
  → Integration of stakeholders

# Literature


- *Andresh et al. (2021): Ökobilanzen im Projekt reFuels – Kraftstoffe neu denken. Forschungsbericht, Karlsruher Institut für Technologie (KIT). DOI: 10.5445/IR/1000141494*
- Guitouni, Martel (1998). Tentative guidelines to help choosing an appropriate MCDA method. *European journal of operational research*, *109*(2), 501-521
- *Haase et al (2022a): Prospective assessment of energy technologies: a comprehensive approach for sustainability assessment. Energy, Sustainability and Society, 12 (20), Article no: 20. doi:10.1186/s13705-022-00344-6*
- *Haase et al. (2022b): Multi criteria decision analysis for prospective sustainability assessment of alternative technologies and fuels for individual motorized transport. Clean technologies and environmental policy, 24 (10), 3171–3197. doi:10.1007/s10098-022-02407-w*
- *Mesa Estrada et al. (2022): Status of MCDA Tool Development. Helmholtz Workshop "MCDA for Sustainability Assessment", 10.11.2022, online*
- Trippe, Techno-ökonomische Bewertung alternativer Verfahrenskonfigurationen zur Herstellung von Biomass-to-Liquid (BtL) Kraftstoffen und Chemikalien, Print on demand. Karlsruhe: KIT Scientific Publishing, 2013.
- Vázquez et al. (2018): Power-to-X technology using renewable electricity and carbon dioxide from ambient air: SOLETAIR proof-of-concept and improved process concept. Journal of CO2 Utilization. https://doi.org/10.1016/j.jcou.2018.09.026
- Wang et al. (2009). Review on multi-criteria decision analysis aid in sustainable energy decision-making. *Renewable and sustainable energy reviews*, *13*(9), 2263-2278.

# Contact

**Dr. Martina Haase**

Phone: +49 721 608-26094

Email: martina.haase@kit.edu