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Addressing uncertainties in the life-cycle assessment of biofuels and renewable fuels

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JCR Ispra

Motivation: Renewable fuels for aviation

Electric flight limited by battery mass

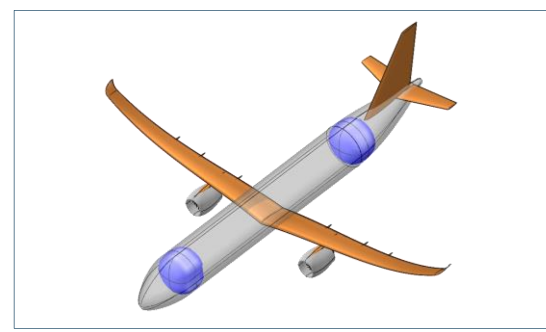
- Bauhaus Luftfahrt Concept Study Ce-Liner
- Target: Cover 80% of air traffic (900 nm range)
- Would require specific energy > 1 kWh/kg

Hybrid electric aircraft concepts still rely on liquid fuel

- From fuel perspective: No change of primary energy carrier, essentially an efficiency measure

Liquefied gasses (LH_2 and LNG)

- Feasible concepts, studies find no or marginal fuel efficiency penalty at aircraft level, turbines remain technology of choice



Sources: M. Hornung, *Ce-Liner – Case Study for eMobility in Air Transportation*, Aviation Technology, Integration and Operations Conference. Los Angeles. 12.8.2013
EU-H2020 Project Centreline: http://cordis.europa.eu/project/rcn/209713_en.html;

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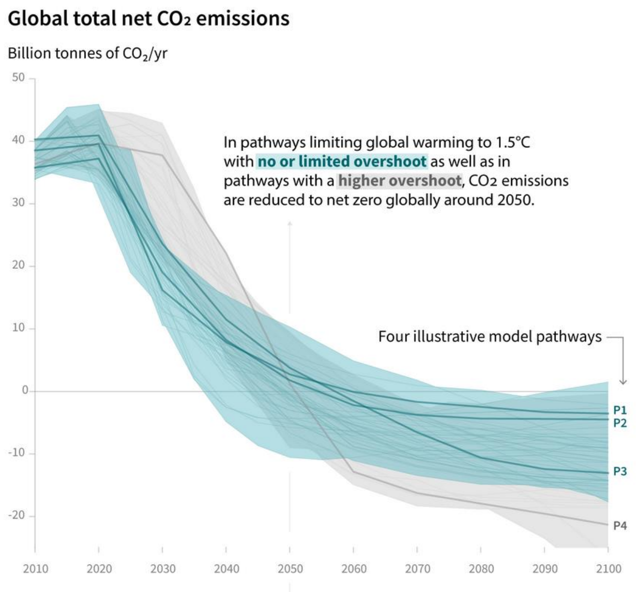
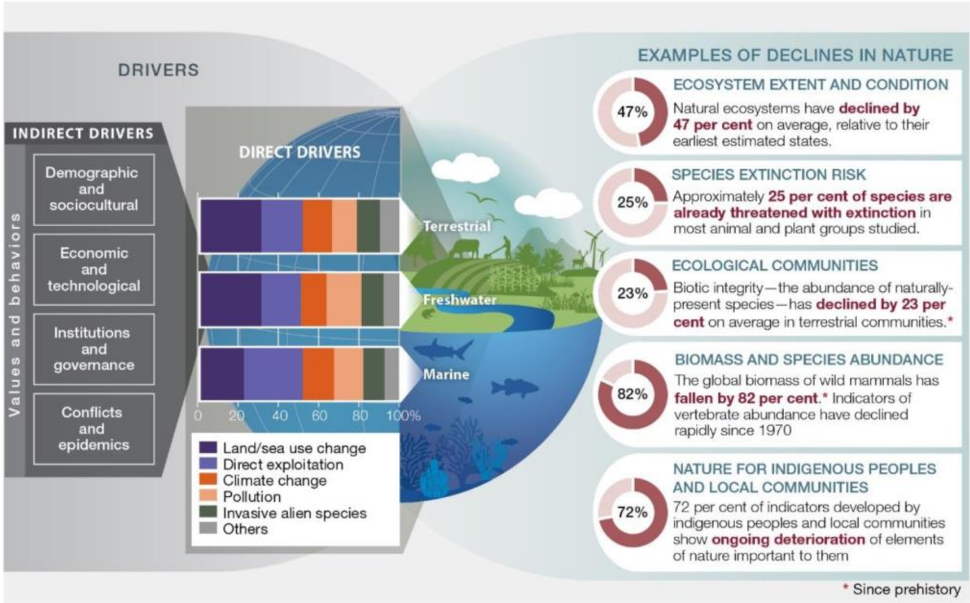
Why is reliable sustainability assessment so important?

- **Sustainability nexus: Very large volumes of renewable fuels required, but biodiversity and ecosystem are already under strong pressure**



Intergovernmental Panel on Climate Change



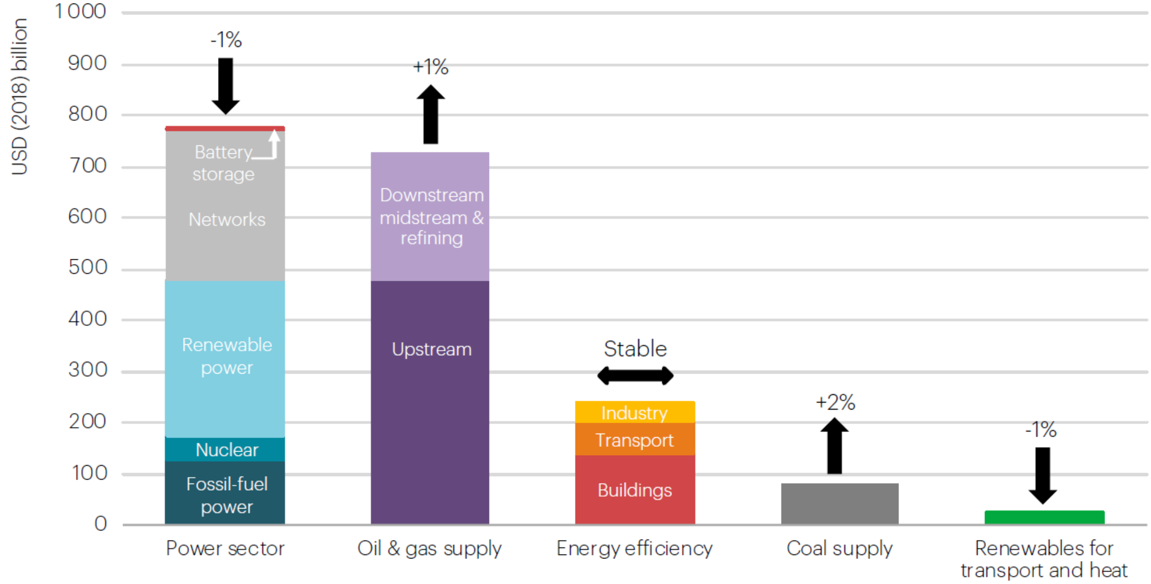
Intergovernmental Platform on Biodiversity and Ecosystem Services

Sources: IPCC Special Report, Global Warming of 1.5 °C, https://www.ipcc.ch/sr15/
IPBES Global Assessment https://www.ipbes.net/news/ipbes-global-assessment-summary-policymakers-pdf

Energy investments in renewables for transport have stalled

Investment in biofuels and renewable fuels not in line with ambitions

Global energy investment in 2018 and change compared to 2017



Source: IEA World Energy Investment 2019, iea.org/wei2019. Allrights reserved.

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Energy investments in renewables for transport have stalled

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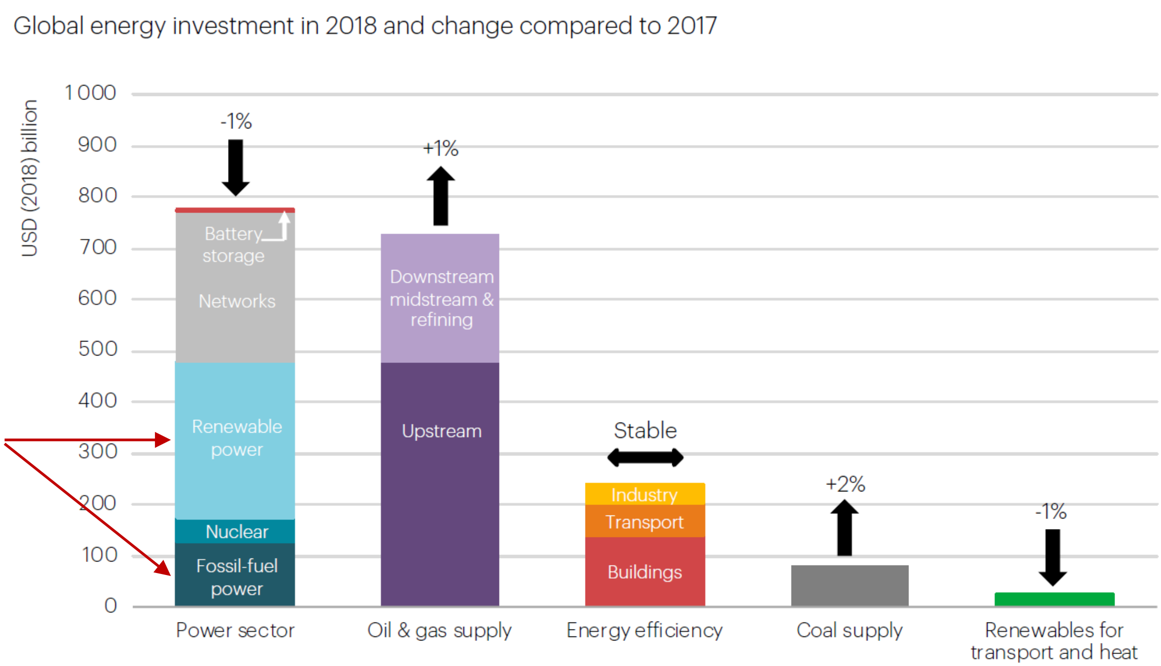
Power Sector:
Investments redirected towards renewables
Continued policy support



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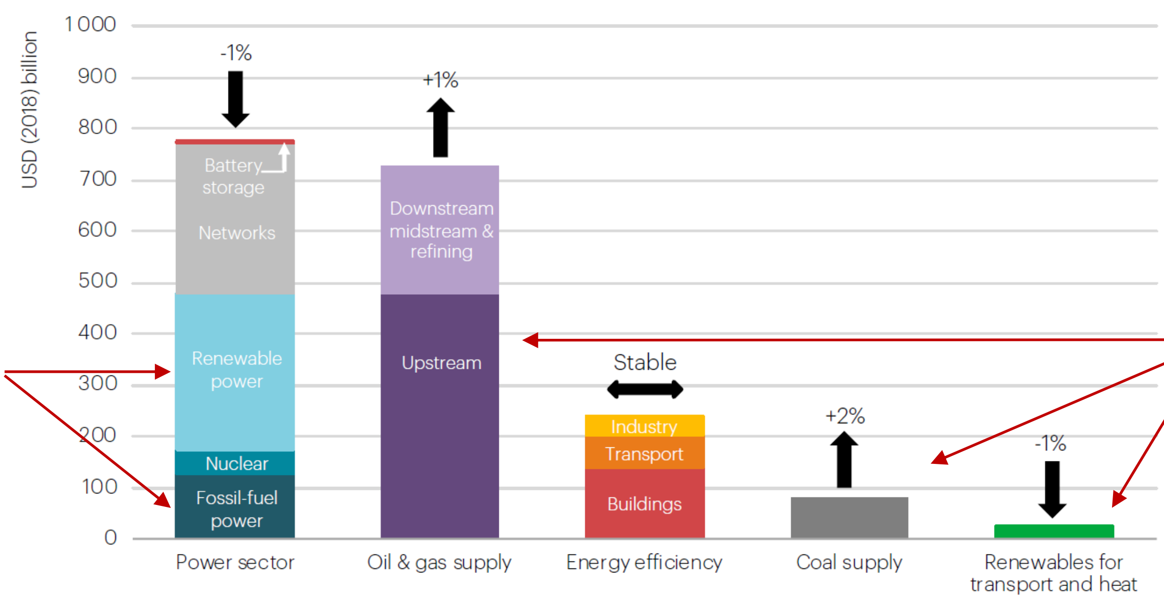


Transport & Fuels:
Persistent fossil dominance
Adaption of policies in response to sustainability concerns

- **Sustainability concerns need to be acknowledged and reliable sustainability assessment is needed to enable investment**

Source: IEA World Energy Investment 2019, iea.org/wei2019. Allrights reserved.

Prospective LCA

- Prospective LCA is most relevant to guide the growth phase of next generation biofuels and renewable fuels

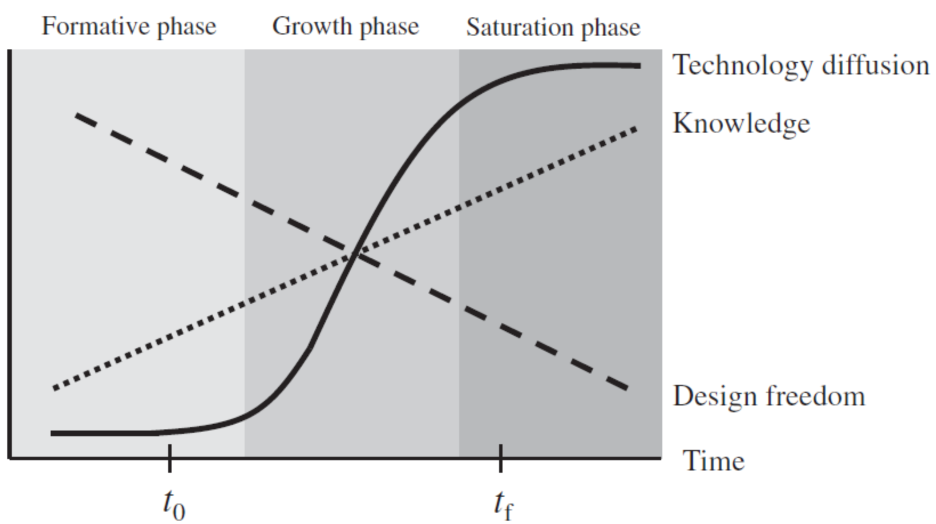


Figure 1 Schematic illustration of the technology diffusion, knowledge, and design freedom curves. In order for an LCA to be prospective, the technology should be in the formative phase or early growth phase at the current time of the assessment (t_0) and should be modeled at a future time (t_f) in the saturation phase or late in the growth phase. LCA = life cycle assessment.

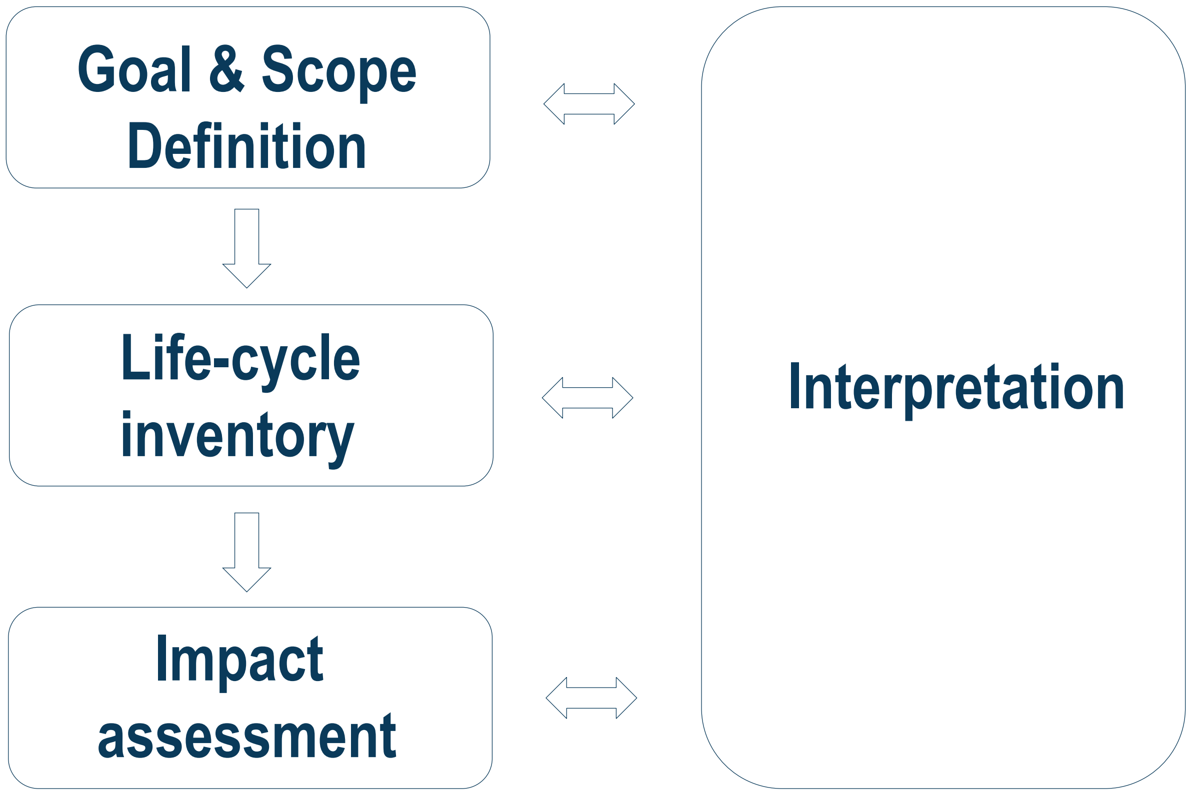
Source: Arvidsson, Environmental Assessment of Emerging Technologies, Journal of Industrial Ecology 22 (6), 1286, 2018

Conventional LCA vs. Prospective LCA

Aspect	*Conventional LCA*	*Prospective LCA*
Definition	System modeled at a current or near-by time	System modeled at a future time
Technology alternatives	Currently existing technologies are studied.	Emerging technologies with relevance for the future are studied.
Foreground system data including production scale	Current foreground system and production scale are modeled. Common data sources include: • life cycle inventory databases • previously conducted LCA studies	A future scenario of the foreground system and production scale is modeled. Valuable data sources include: • scientific articles • patents • expert interviews • unpublished lab results • process simulations
Background system data	Current background system is modeled.	A future scenario of the background system is modeled. Important to avoid temporal mismatch between the foreground and background systems. Potential for not modeling background system at all.

Source: Arvidsson, Environmental Assessment of Emerging Technologies, Journal of Industrial Ecology 22 (6), 1286, 2018

The four phases of LCA



Basic computational structure of LCA

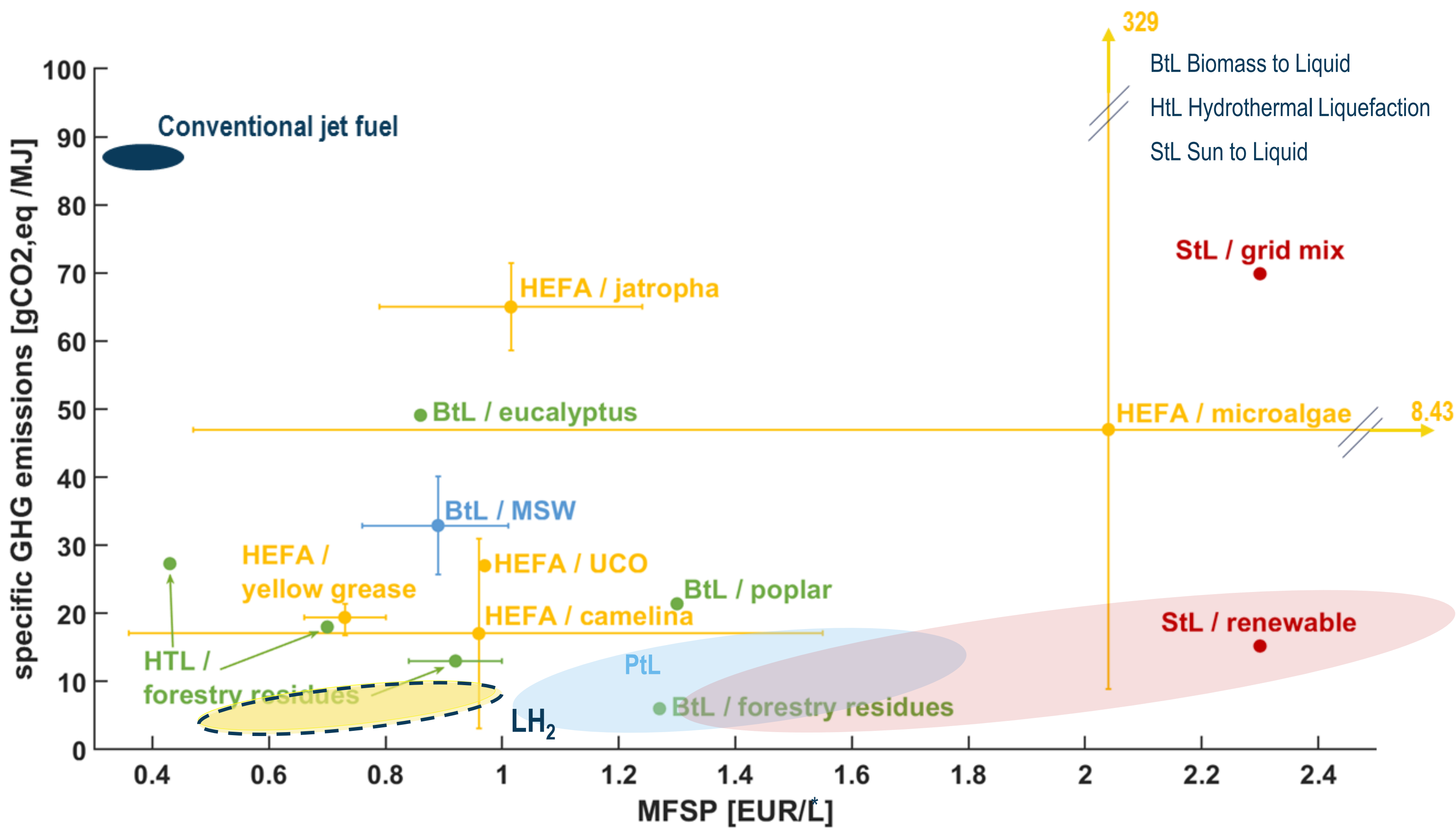
- **Deterministic evaluation: The evaluation itself does not involve any uncertainty**

$$s = A^{-1}f$$

- **Uncertainties are submerged in**
  - The final demand vector f, that represents the investigated system (including all uncertainties associated to system definition and modelling)
  - The technology matrix A, which establishes the basis for the evaluation (including all uncertainties with the inventories)
- **A proper sensitivity analysis can identify the main contributions to uncertainty**
  - Validate A and f with respect to main drivers of uncertainty

Sources: The Computational Structure of Life Cycle Assessment, Heijungs and Suh, Springer 2002

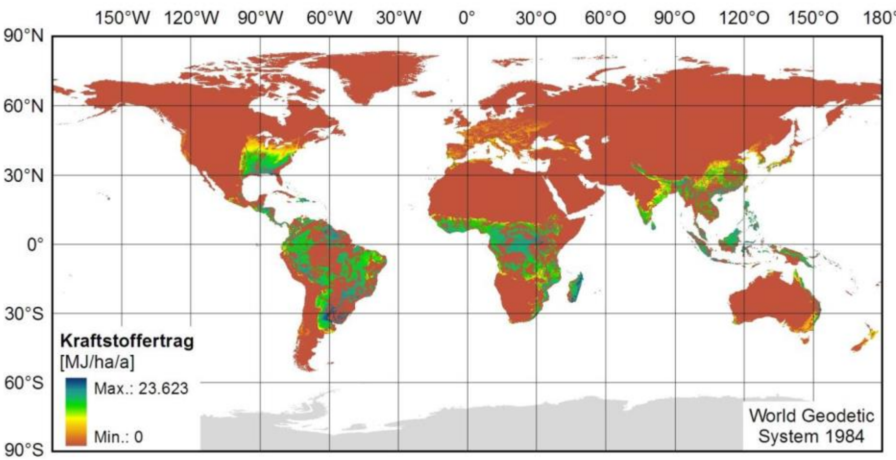
Mapping in CORE-JetFuel: Complex results

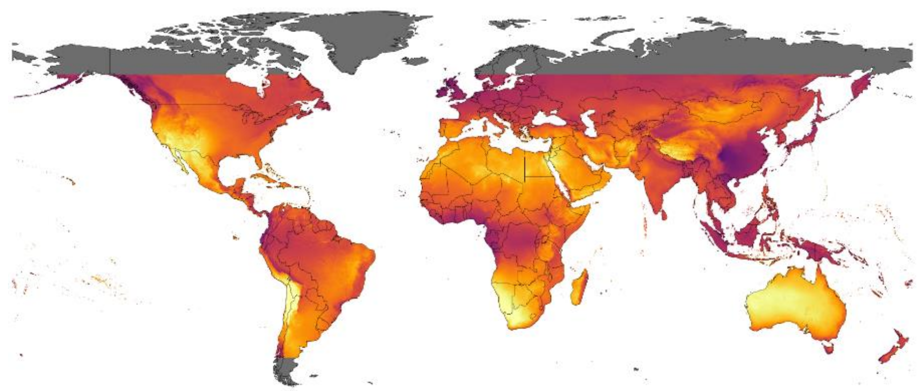


[* per L kerosene-eq]

Geographical variation of LCA results

- LCA results for almost all renewable fuel pathways tend to vary with location
- Technically, this is not an uncertainty, it is a geographical distribution of results

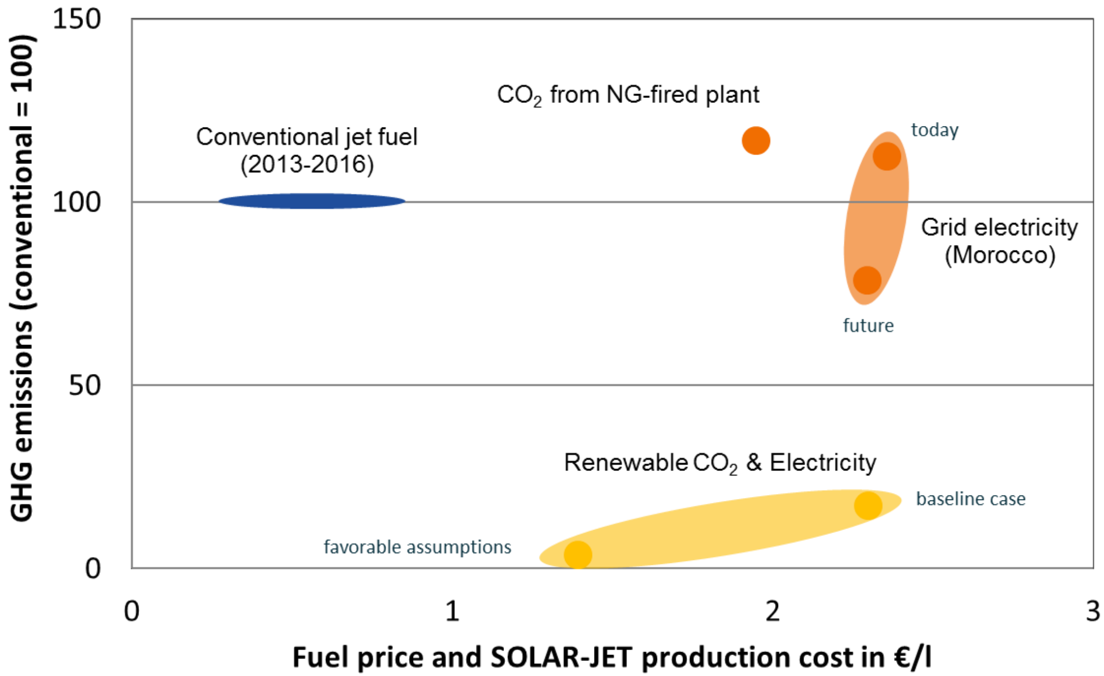




Sources: Left: Productivity map for miscanthus giganteus, Right: Solar Resource (DNI)

Variability of results with respect to design choices and allocation

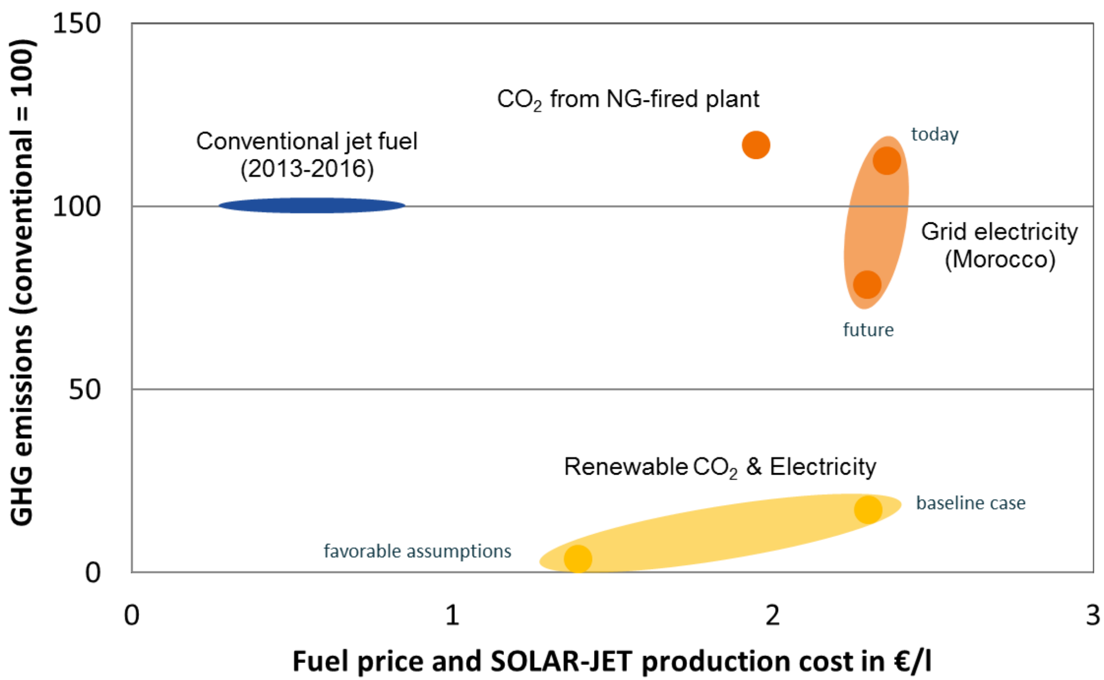
- **Design choices, choices of boundary boxes or choices of allocation methods yield discrete jumps in the result**
- **Distribution around a scenario cases reflect uncertainty of input parameters**



Source: C. Falter, *Climate Impact and Economic Feasibility of Solar Thermochemical Jet Fuel Production*, Environ. Sci. Technol., 2016, 50 (1)

Variability of results with respect to design choices and allocation

- **From a scientific perspective these jumps due to design choices should be accepted in a similar way as uncertainty of input parameters is accepted**



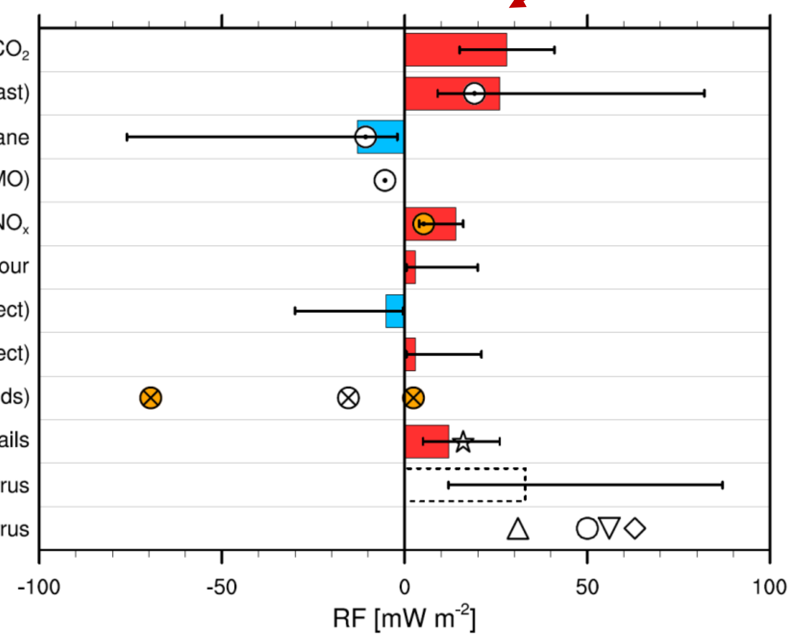
Source: C. Falter, *Climate Impact and Economic Feasibility of Solar Thermochemical Jet Fuel Production*, Environ. Sci. Technol., 2016, 50 (1)

Upcming issue: Impact of aviation fuels on non-CO_2 climate effects

- LCA should cover the dominating effects, but LCA is only sensitive to effects that are covered by the scope of the analysis

CO_2 effect resulting from fuel combustion

Potentially large non-CO_2 contributions resulting from fuel combustion at flight altitude



Sources: Grewe, *Mitigating the Climate Impact from Aviation: Achievements and Results of the DLR WeCare Project*, Aerospace 2017, 4, 34;

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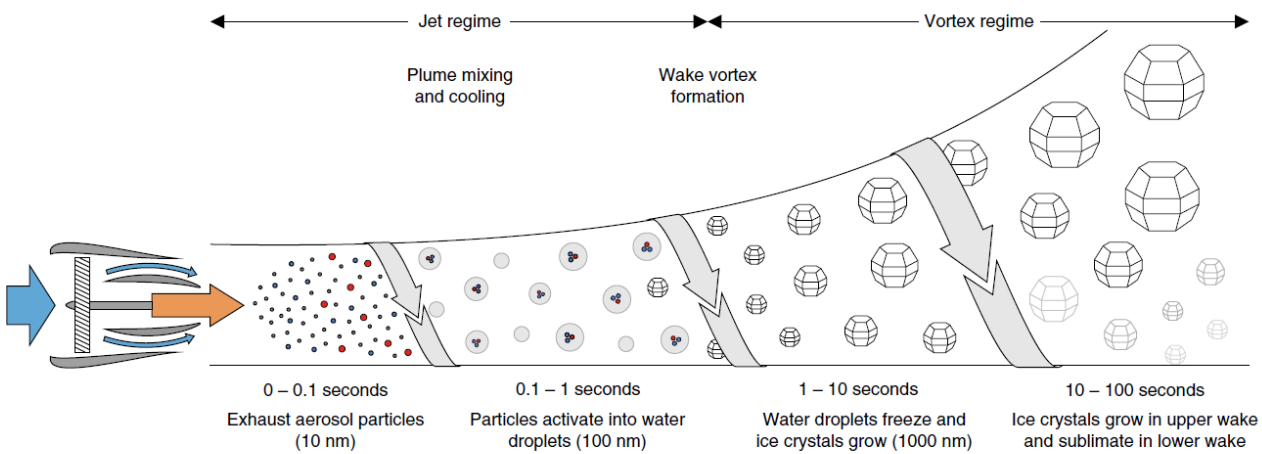
Non-CO_2 climate effects also depend on fuel properties

- **Contrail, cirrus and aerosol effects critically depend on aromatics and Sulphur**
- **H_2O effects and NO_x formation drastically change for non drop-in fuels, e.g. LH_2**



- **How can we address non-CO_2 climate effects in well-to-wake LCA of aviation biofuels and renewable fuels?**

Sources: Kärcher, *Formation and radiative forcing of contrail cirrus*, Nature Communications (2018) 9:1824
DOI: 10.1038/s41467-018-04068-0

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Conclusions

- **Prospective LCA is relevant for emerging biofuel and renewable fuel pathways, which are in the formative and early growth phase**
- **Sensitivity analyses are required to identify and address the main drivers of uncertainty**
- **Design choices can lead to jumps in the results**
  - This should be understood as a feature of LCA, not as a methodological failure
  - Typical e.g. for allocation of CO_2 emissions in CCU pathways

- **How can we address non-CO_2 climate effects in well-to-wake LCA of aviation biofuels and renewable fuels?**

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Thank you for your attention

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