

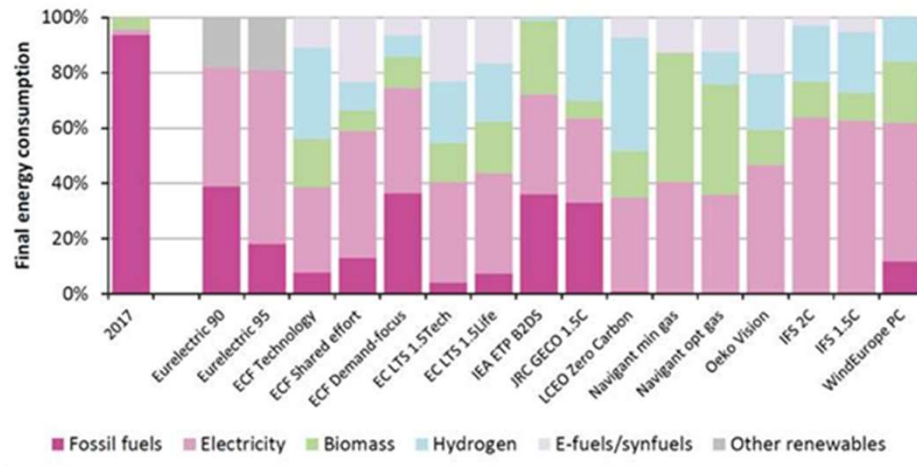
Synergies and Trade-Offs Between Hydrogen Demand, Carbon and Energy Efficiency in Advanced Biofuel and Bio- electrofuel Pathways

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Context & Motivation



EU28 Transport Energy Demand in 2050 ($\geq 90\%$ Reduction Scenarios)

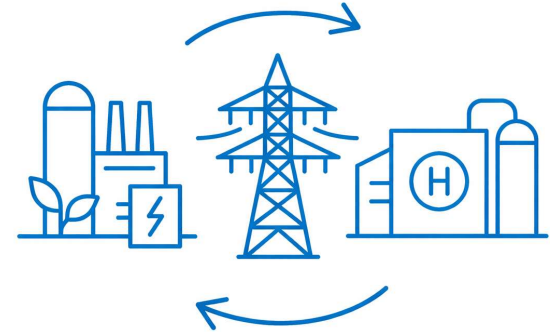
Source: Tsiropoulos et al., 2020, JRC Report

- By 2050: Biomass, H₂ & e-fuels supply ~40–60% of transport energy in most scenarios
- Cross-sector integration: electricity–hydrogen–biofuels
- Beyond GHG: multidimensional performance metrics



Research Aim & Objectives

Aim: To quantify hydrogen, carbon, and energy efficiency trade-offs in advanced biofuel and bio-electrofuel pathways



1. Cataloguing the **definitions** and **boundaries** used in the literature
2. Quantitatively comparing $\eta_{(C)}$, $\eta_{(E)}$ and HR
3. Identify **trade-offs and** assess **sensitivities**

Selected Pathways: Bio-Dimethyl ether (**Bio-DME**), Bio-Fischer-Tropsch (**Bio-FT**), **Fast Pyrolysis**, Hydroprocessed Esters and Fatty Acids (**HEFA**), Hydrothermal liquefaction (**HTL**), Alcohol to Jet (**ATJ**)



Defining Carbon Efficiency

$$\eta_C = \frac{C_{\text{fuel product}}}{C_{\text{feedstock input}}}$$

Feedstock-to-product Carbon Efficiency

$$\eta_C = \frac{C_{\text{main product}} + C_{\text{valuable co-products}}}{C_{\text{feedstock}}}$$

Useful-product Carbon Efficiency

$$\eta_C = 1 - \frac{C_{\text{emitted (CO}_2, \text{CO, CH}_4)}}{C_{\text{input}}}$$

Carbon Yield (Carbon Retention)

$$\eta_C = \frac{C_{\text{fuel}}}{C_{\text{biomass}} + C_{\text{captured CO}_2}}$$

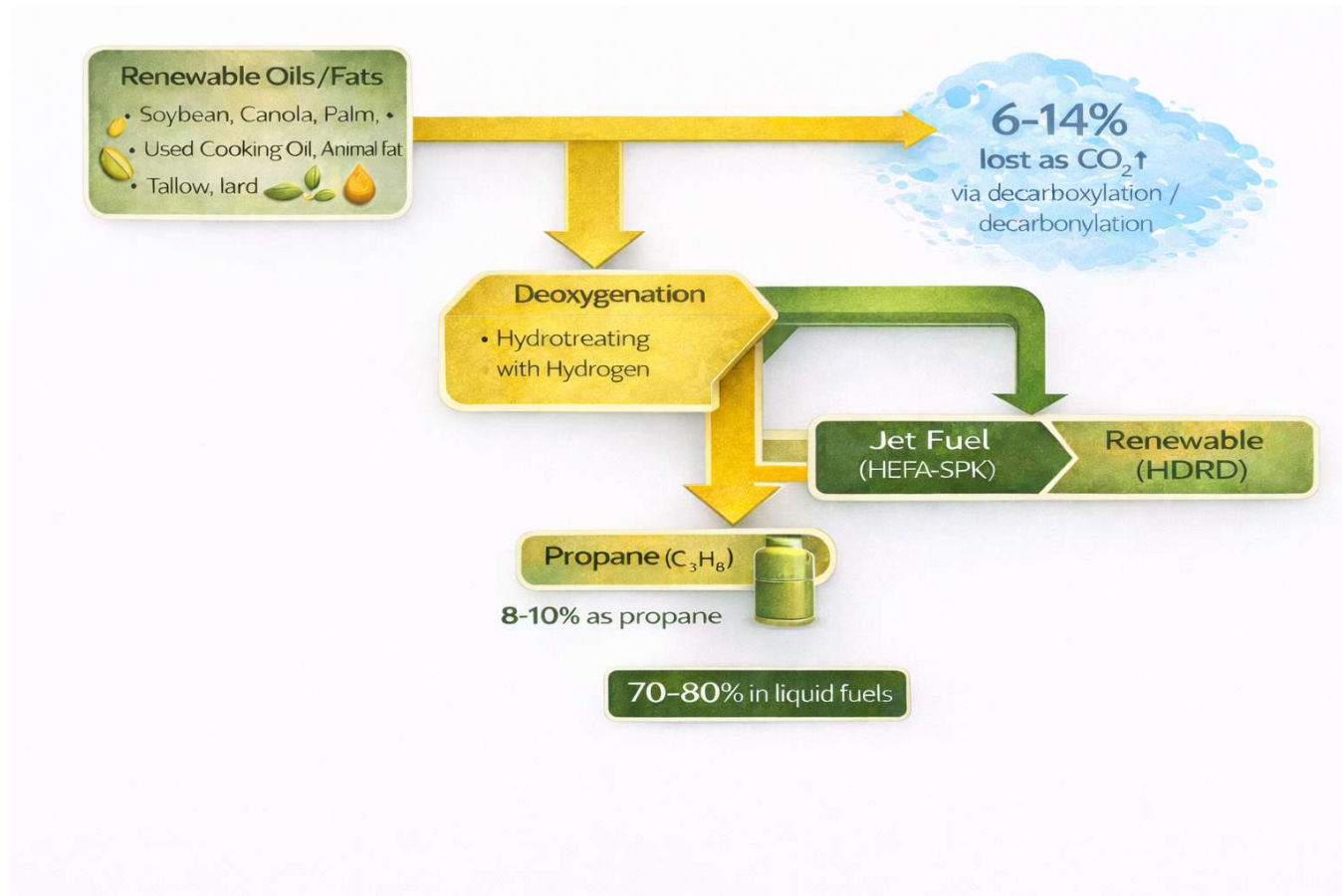
System Carbon Efficiency

$$\text{Carbon efficiency} = \frac{C_{\text{fuel}}}{\text{GHG}_{\text{lifecycle}}}$$

Climate-oriented Carbon Efficiency

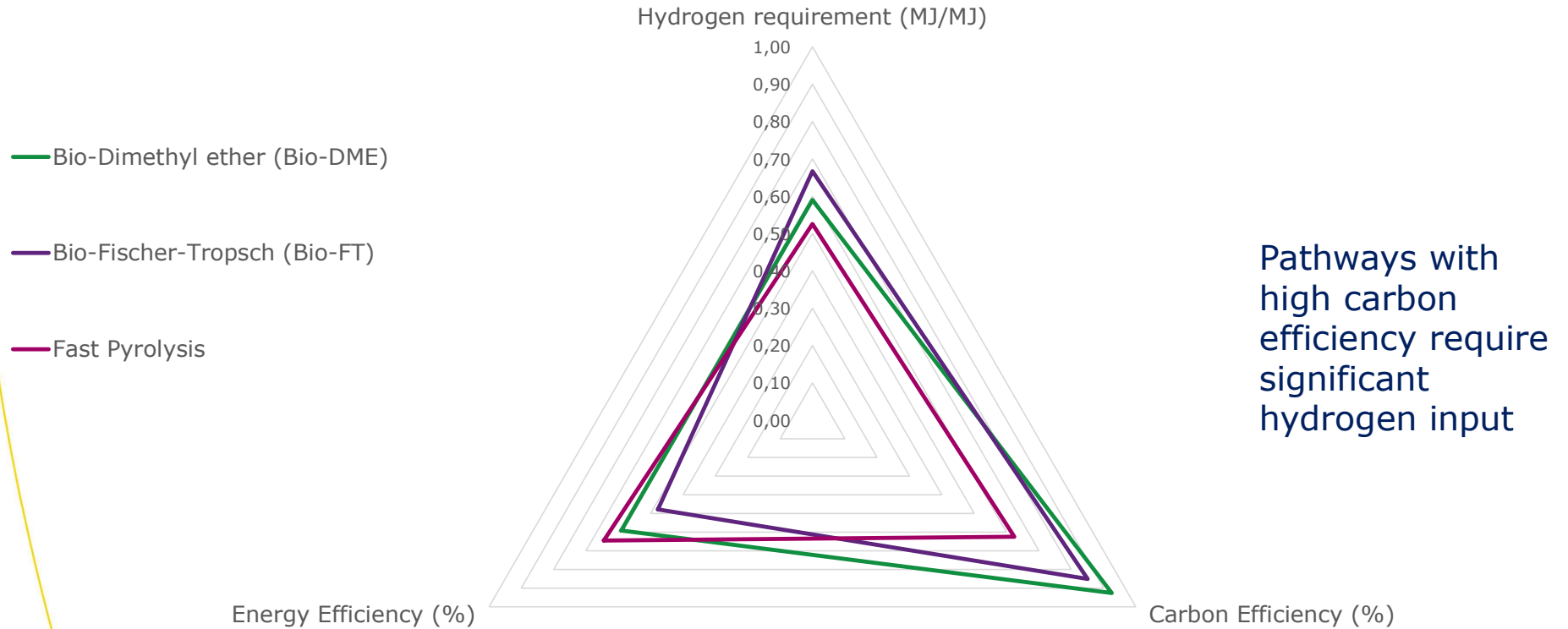


Example of Carbon Mass Balance: HEFA



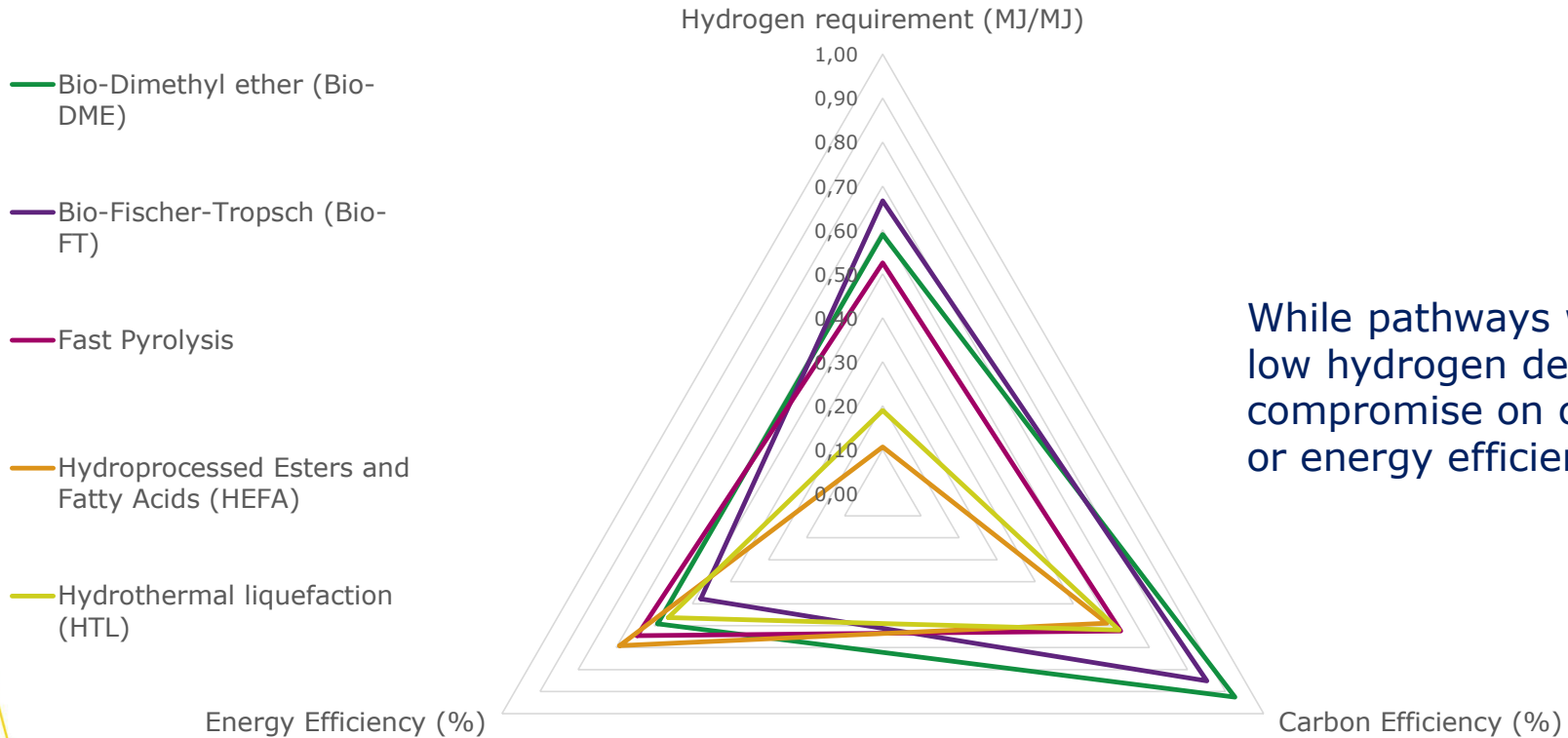


Trade-offs between Carbon-Energy-Hydrogen





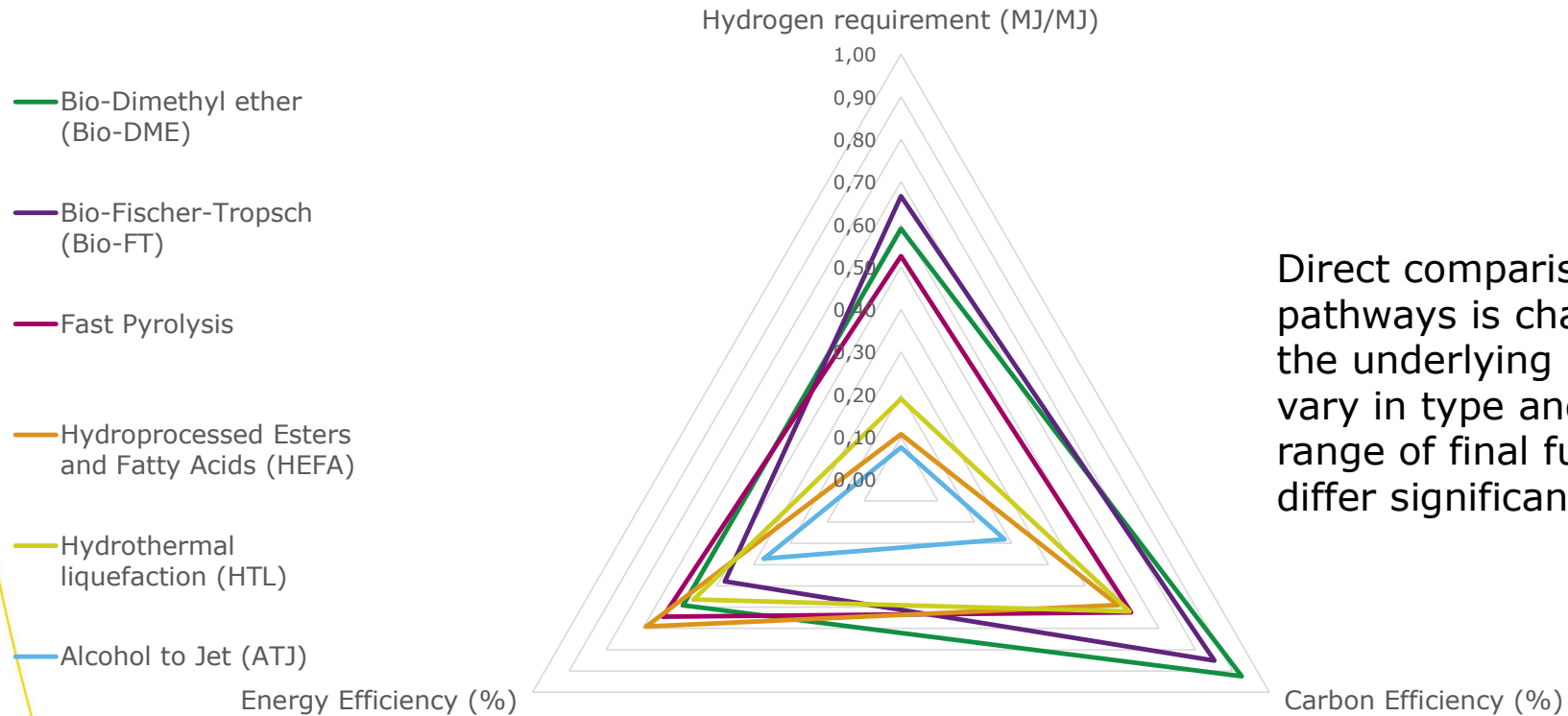
Trade-offs between Carbon-Energy-Hydrogen



While pathways with low hydrogen demand compromise on carbon or energy efficiency



Trade-offs between Carbon-Energy-Hydrogen



Direct comparison across pathways is challenging, as the underlying feedstocks vary in type and quality, and range of final fuel products differ significantly.

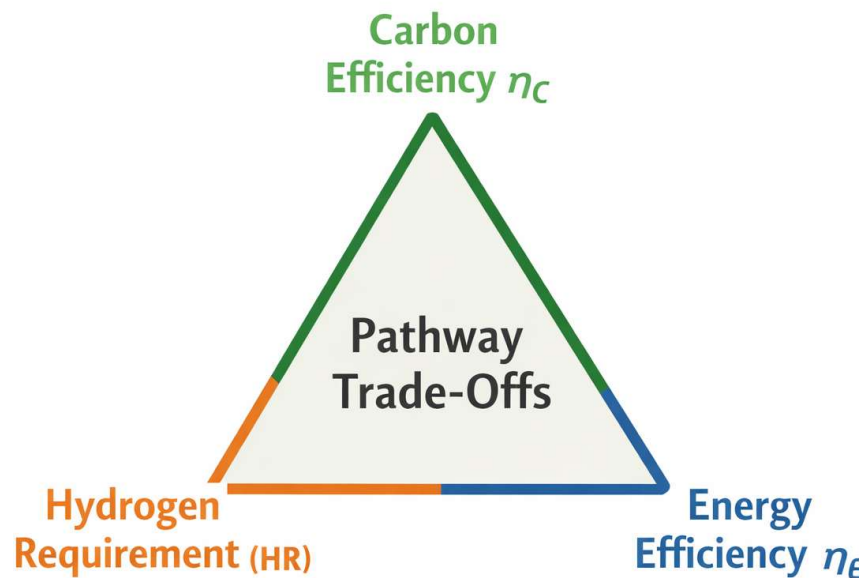


++ very favorable | + favorable | - unfavorable | -- strongly unfavorable

Pathways	Carbon efficiency (η_C)	Energy efficiency (η_E)	Hydrogen requirement (HR)	Tech maturity	Main bottleneck
HEFA	High (++)	High (++)	Medium - Low (+)	High (++)	Sustainable lipid availability
Bio-FT	Medium	Medium	Medium	Medium	Carbon losses + high CAPEX
ATJ	Medium	Medium	Medium-Low (+)	Medium	Alcohol yields + upgrading complexity
HTL	High (++)	Medium	Medium	Low-Medium (-)	Oil upgrading + heterogeneity
Fast Pyrolysis	Low-Medium (-)	Medium	High (--)	Low-Medium (-)	Bio-oil instability + deep upgrading
Bio-DME	Medium	Medium	Medium	Medium	Infrastructure + market uptake



Take Aways

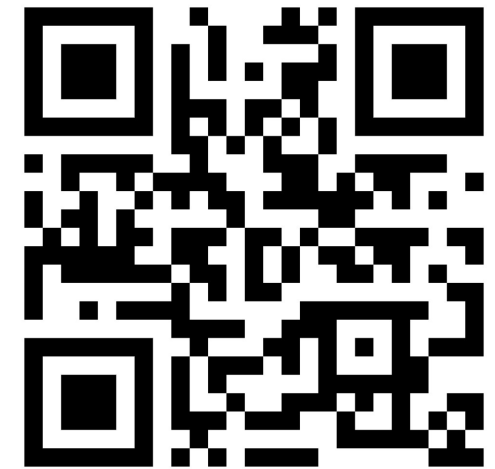


- Results are highly sensitive to **system boundaries** and **starting biomass type**
- **No single pathway dominates** across η_C , η_E , and HR, Pathway selection reflects a strategic balance between **biomass efficiency** and **renewable hydrogen availability**



Thank you.

Questions&Discussions
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Access full report!



References

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