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Techno-Economic Analysis

How to become SAF ready? How to make SAF happen?

SAF Training for ACI Africa & AFRAA

23.-25.04.2025, Arusha, Tanzania

Global Gateway

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An Agency of the European Union

Topic

Techno-Economic Analysis (TEA)

Dr. Fabian Schmitt

@ fschmitt@cbr-partner.de

CBR Sustainability Partners

Technology Expert

Dr. Fabian Schmitt is a professional in green chemicals such as sustainable aviation fuels with profound knowledge in chemical conversion technologies with expertise in electrochemical processes, electrochemical and thermochemical conversion of carbon dioxide to produce base chemicals, as well as methanol and FT-synthesis. Convinced, that green transition is an interdisciplinary and international effort that needs to be holistically and jointly addressed from technology, business and regulatory perspective.

Consulting Focus @ CBR Sustainability Partners

- Technology assessments, feasibility studies and techno-economic analysis in the field of renewable gases and liquids, hydrogen, Power-to-X, sustainable fuels (SAF) and green chemicals
- Expertise in regulatory policies with focus on renewable fuels, such as SAF
- Focus on renewable fuel production technologies, feedstock availabilities and CO_2 reduction potentials

Education

- PhD in Chemical Engineering, TU Darmstadt, Germany
- Master in Chemical Engineering, TU Darmstadt, Germany / Aalto University Espoo, Finland
- Bachelor in Chemistry, TU Darmstadt, Germany

Topic

Case Study:
Tool for early-stage TEA of SAF Production pathways

Esther Hegel

@ Esther.hegel@rsb.org

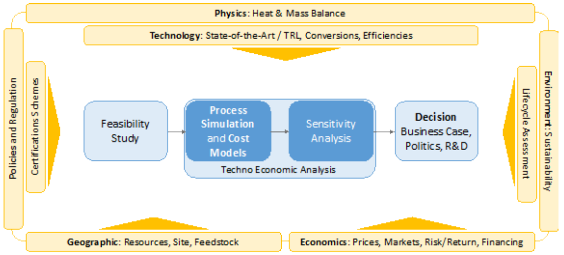
Roundtable on Sustainable Biomaterials (RSB)

EU Project Manager, PhD

Esther advances sustainable biomanufacturing through the assessment of novel biorefinery concepts.

- Bioprocess Engineering Diploma (Dipl.-Ing.)(Karlsruhe Institute of Technology (KIT), Germany, 2015)
- PhD in Industrial Biotechnology (DSM Biotechnology Center Delft & University of Groningen, Netherlands, 2020) as Marie Curie Scholar (funded by European Commission)
- Research Project Manager Bioeconomy and Biotechnology (DECHEMA e.V., Germany, 2020-2024) → LCA and market assessment of novel bio-based production routes (e.g., from CO_2, waste, sugars)
- EU Project Manager (Roundtable on Sustainable Biomaterials (RSB), Germany, since 2024) → LCA and TEA of fuels and materials from sustainable resources

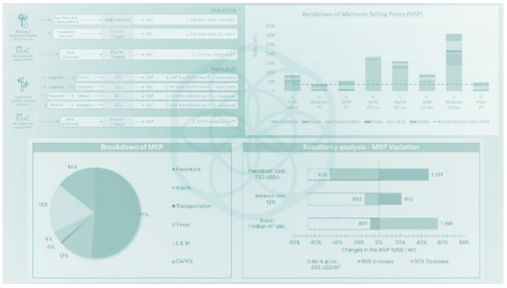
Guiding questions



What is a techno economic analysis?

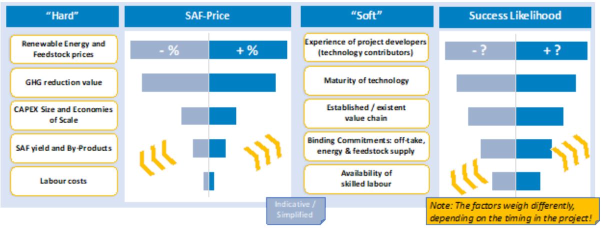
What are the inputs and constrains of a TEA?

RSB®



TEA Case Study:

How is a TEA tool developed, advanced and maintained?



What is a TEA's scope?

How to facilitate and increase its reliability?

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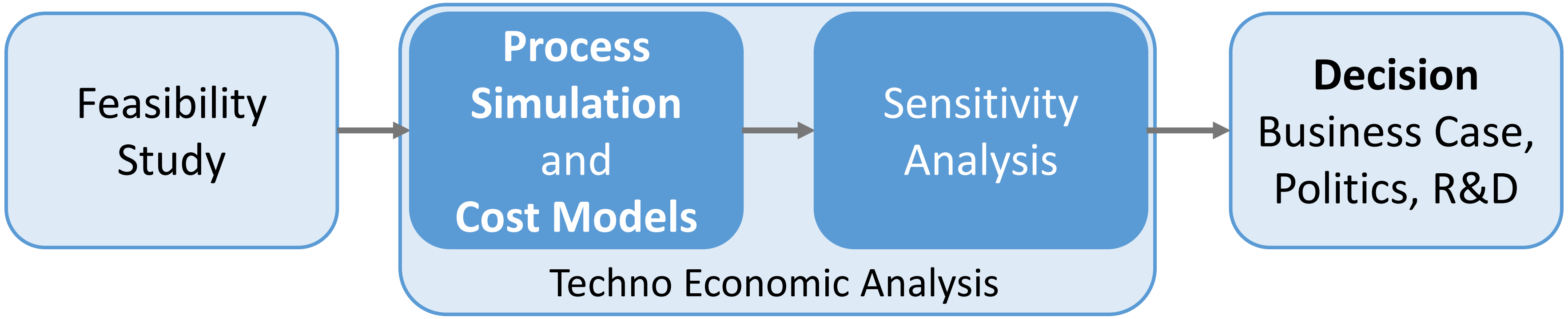
Objectives and Scope of a Techno-Economic Analysis (TEA)

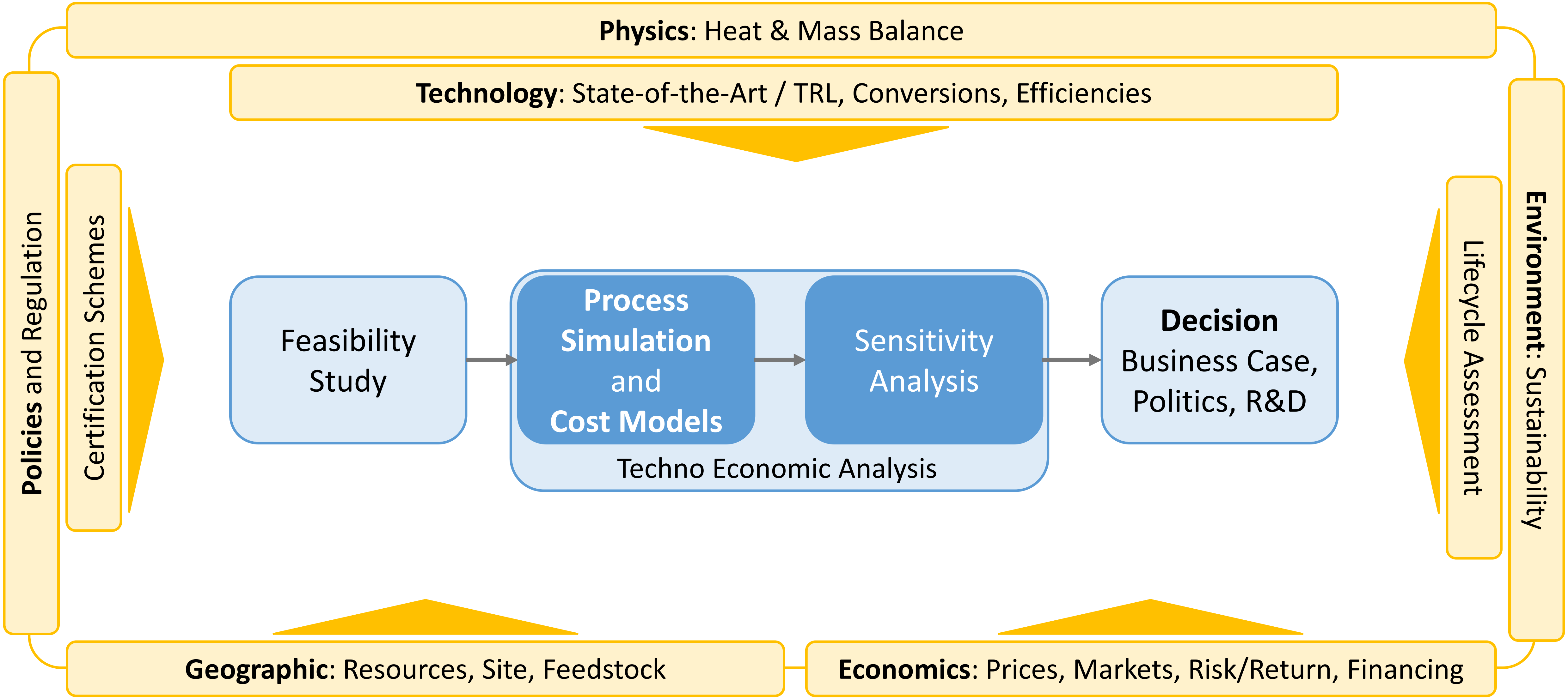
- Comprehensive evaluation method used to assess the **technical and economic feasibility** of a project or process.
- It **combines engineering principles** with **economic analysis** to **determine costs, efficiencies, and potential returns**.
- Includes detailed **process simulations, capital and operational cost estimations, and performance metrics**.
- Actual **use-case** to be defined: Comparison of routes, first estimate of costs, bottle-necks, etc.



- A **sensitivity analysis** is conducted to evaluate how changes in input variables affect **economic viability**.
- It provides **quantitative insights** that help guide decisions on project development and investment.

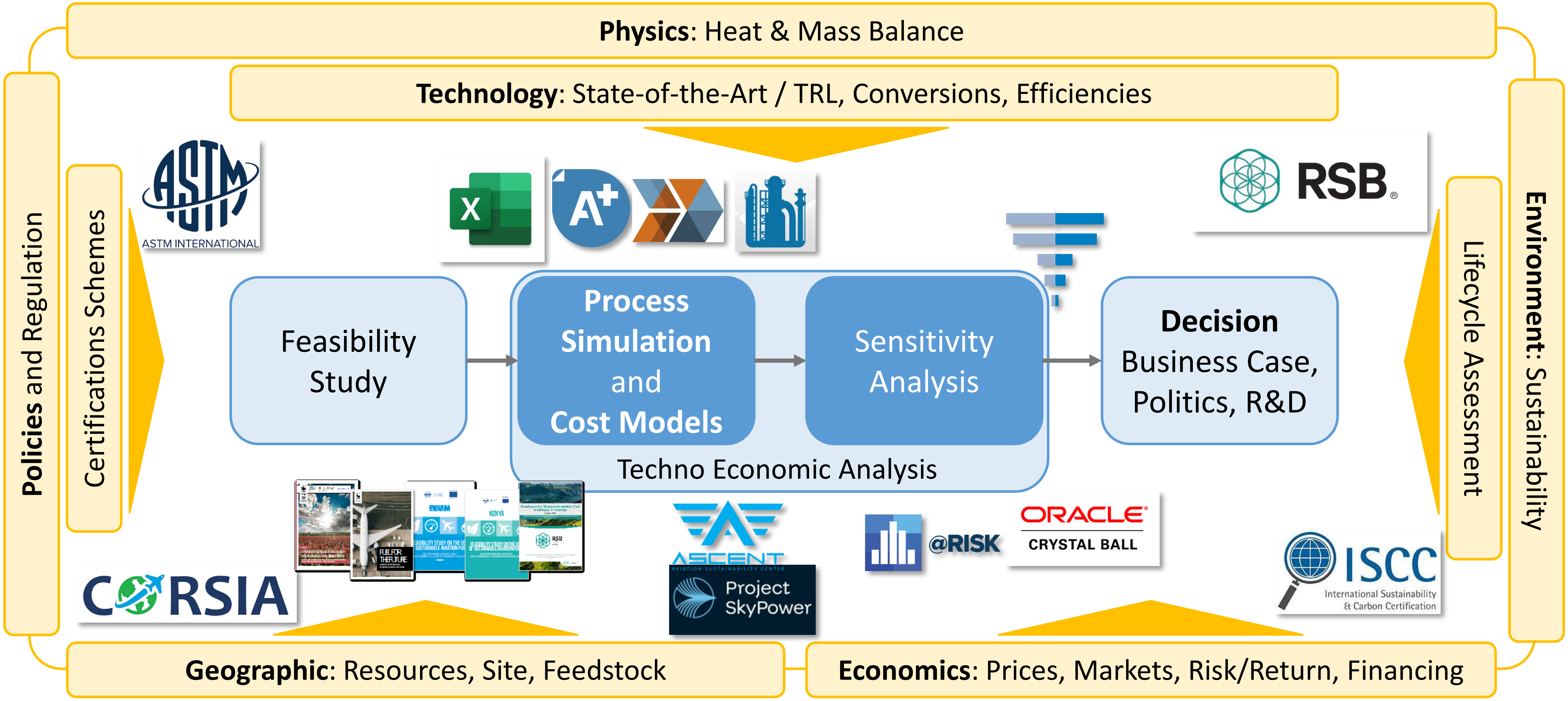
Source: CBR Sustainability Partners 2024

Inputs and constrains for a Techno-Economic Analysis (TEA) in SAF



Source: CBR Sustainability Partners 2024

TEA is a multidisciplinary, quantitative evaluation method

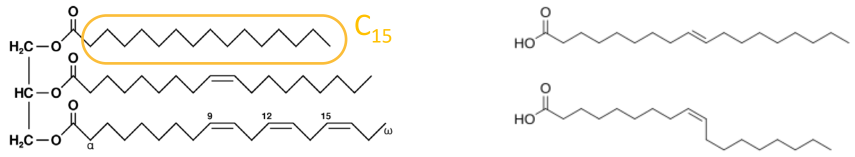


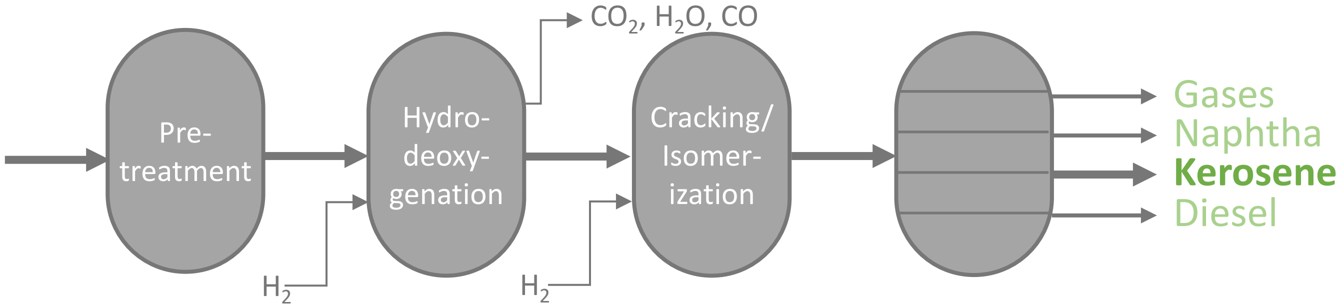
Source: CBR Sustainability Partners 2024

Process flow diagrams & heat and mass balances as basis for TEA

HEFA

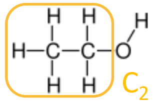
Esters and fatty acids
Contain structures very similar to Jet fuel components, that need to be split and upgraded.

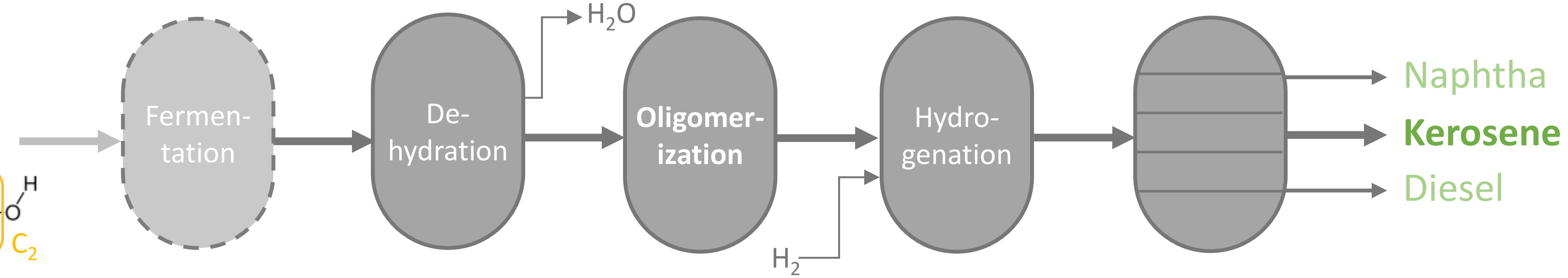




AtJ

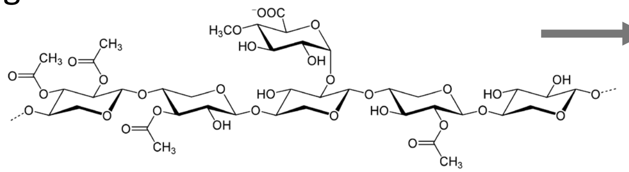
Alcohol (ethanol, butanol)
Well defined feedstock from fermentation (1^{st}G sugars, 2^{nd}G lignocellulosic biomass, woody crops, agricultural residues/waste).
C-chain-length needs to be increased (oligomerization).





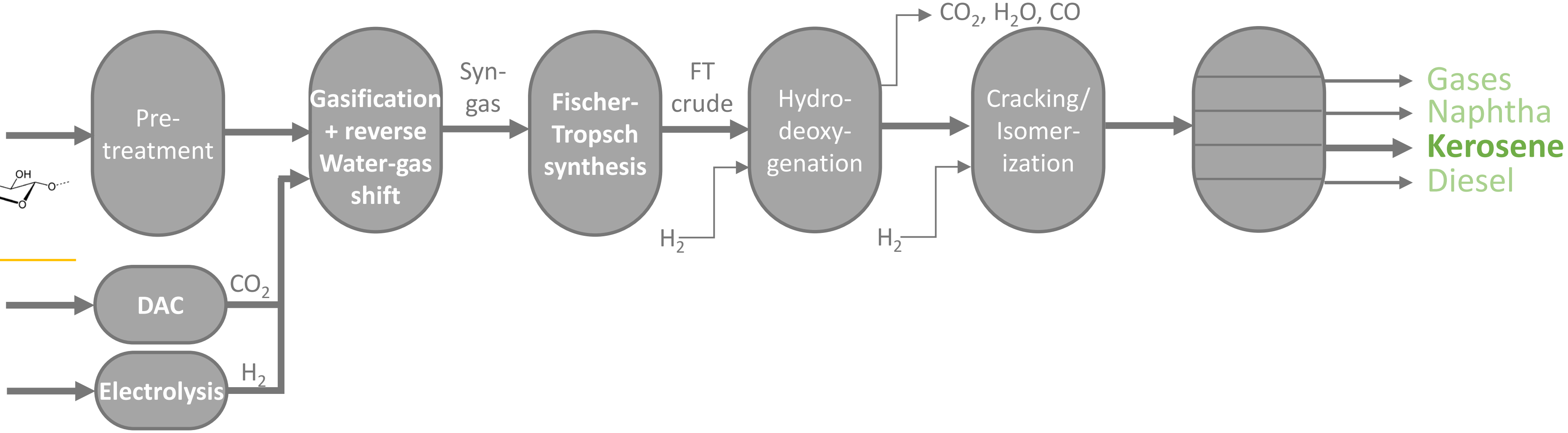
BtL

Lignocellulosic biomass (Xylan)
Chemically diverse, solid, hetero-geneous feedstock.



PtL

Direct Air Capture of CO_2
and **Electrolysis** of water
running on electrical power



For a reliable TEA, it is crucial to underlay a consistent data set for feed, utility, and product prices.

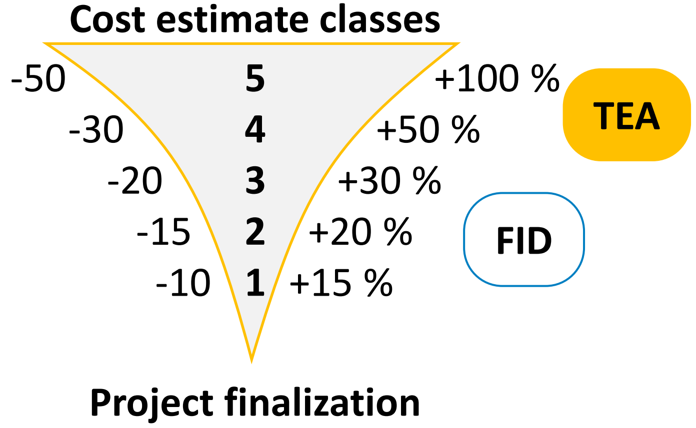
Cost drivers

- Feedstock and logistics (HEFA and electricity depending on location)
- CAPEX: FOAK-character, EPC, economy of scale
- Energy (especially PtL)
- Finance costs / risk premium

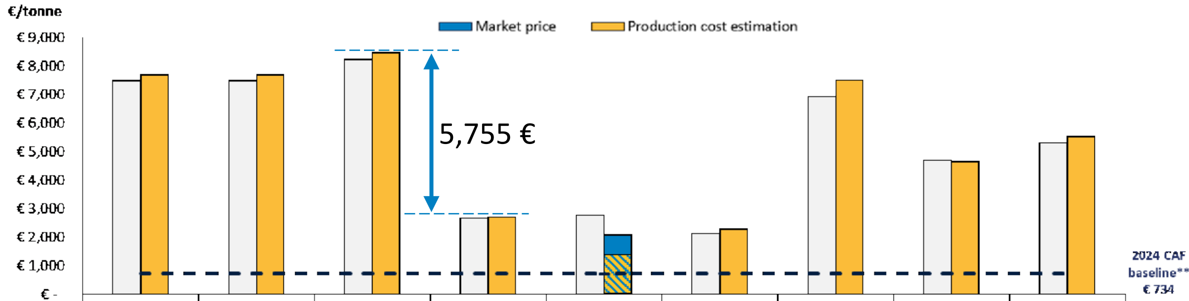
Path-dependent

SAF pricing

- SAF is no commodity, there is no free market established
- Depends on cost of production and regulatory requirements
- Based on bilateral agreements



TEAs are located **early in a project lifetime**. Detailed engineering narrows down the estimates to FID acceptable certainties. The classes at the according project milestones do **not necessarily reflect FOAK character** of these projects.



	Synthetic aviation fuels from industrial CO_2	Synthetic aviation fuels from biogenic CO_2	Synthetic aviation fuels from atmospheric CO_2	Advanced aviation biofuels	Aviation biofuels *	Recycled carbon aviation fuels	Renewable H_2 aviation fuels	Low-carbon H_2 aviation fuels	Synthetic low-carbon aviation fuels
2023	€ 7,500	€ 7,500	€ 8,225	€ 2,675	€ 2,768	€ 2,125	€ 6,925	€ 4,700	€ 5,300
2024	€ 7,695	€ 7,695	€ 8,470	€ 2,715	€ 2,085	€ 2,280	€ 7,520	€ 4,655	€ 5,525

**The bar with blue and yellow stripes represents the 2024 production cost estimation for aviation biofuels (provided for informational purposes).*

*** For reference: The 2023 CAF price was 816 €/tonne.*

Estimated prices for SAF strongly depend to the pathway, due do **varying feedstock and CAPEX intensities**. The ranges within and between studies reflect the **uncertainties of the nascent market**.

Key cost drivers determining cost of production, here exemplary PtL

Cost Drivers deciding the Cost of Production of PtL SAF plants	
CAPEX	• Equipment Costs of Units • Total CAPEX Cost Factor
Feedstocks	• H_2O • CO_2
Utilities	• Electricity (Renewable) • Cooling Water
By-products	• Naphtha • Purge
Operations	• O&M • Efficiency • Plant Availability
Financials	• Cost of Capital • Financing Architecture • Public Grants

Based on pathway, technology maturity and process simulation

LCOP = minimum sales price of SAF

Path-dependent

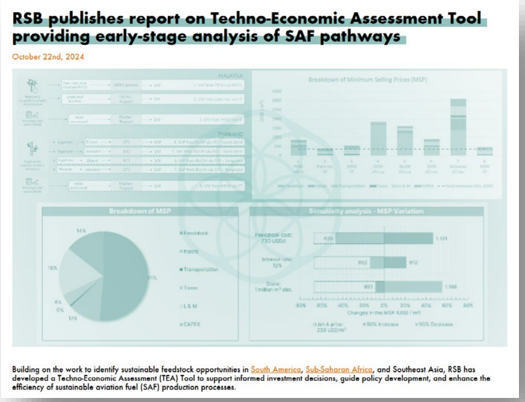
Cost of Production (COP)

+Cost of Capital (WACC)

Levelized Cost of Production (LCOP)

Source: CBR Sustainability Partners 2024

Deep-Dive:
TEA tool development and how to advance and maintain it



Report published 2024 here!

Case Study:
Tool for early-stage TEA of SAF production pathways

Esther Hegel
Roundtable of Sustainable Biomaterials (RSB)

www.rsb.org

Case Study:
Tool for early-stage TEA of SAF production pathways

Esther Hegel, PhD

SAF Training for ACI & AFRAA Tanzania

25 April 2025

Agenda

Introduction

Project overview

Decarbonising aviation sustainably in Southeast Asia

Generously funded by The Boeing Company and Standard Chartered

Sustainable Feedstock for SAF production	Literature review and sustainability analysis of bio-based feedstock availability in Southeast Asia. Publication date: end of August.
SAF Techno-Economic Assessment	Techno-economic analysis of 8 feedstock-pathway combinations for SAF production with TEA Tool for SAF
Stakeholder engagement	Organisation of regional conference (May 2023) and participation in stakeholder meetings and events

TEA Tool: Development Timeline

INITIAL DESIGN & DATA COLLECTION

Technical review of existing TEA tools, methodology description, selection of pathways, data collection

INTERNAL VALIDATION

Perform TEA for selected SAF pathways in the tool & data refinements

USER INTERFACE

Develop & validate new advanced user interface with project advisory group

EXTERNAL VALIDATION

Collect & incorporate feedback from stakeholder validation workshops (advisory group)

FINAL PRODUCTS

- TEA Tool V2.10 finalised
  - User guideline
  - Video tutorials
  - Demo calculations
  - Report (public)

July 2024

Goal & Scope of the TEA Tool

Why a TEA Tool for SAF?

PURPOSE

Provide a simplified tool too assess the feasibility and cost-effectiveness of new SAF pathways by combining technical performance data with economic analysis.

KEY INSIGHTS

- Provides insights into economic indicators like capital and operational costs.
- Identifies cost drivers and areas for potential improvement.

BENEFITS

- Provides financial viability information to stakeholders, policymakers, and investors.
- Supports investment decisions and policy development.
- Encourages advancement of promising SAF technologies.

How does the tool look like?

TOOL DESIGN

- Created as an Excel spreadsheet for offline use without special software.
- Supports modelling multiple pathways by saving multiple copies.

CUSTOMIZATION

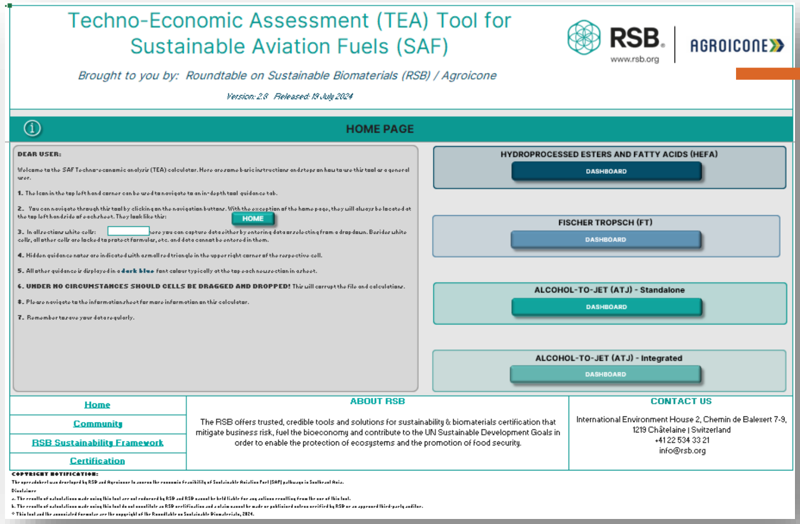
- Allows integration of country- and pathway-specific data using primary sources.
- Default values available in case primary data is missing.

PATHWAYS

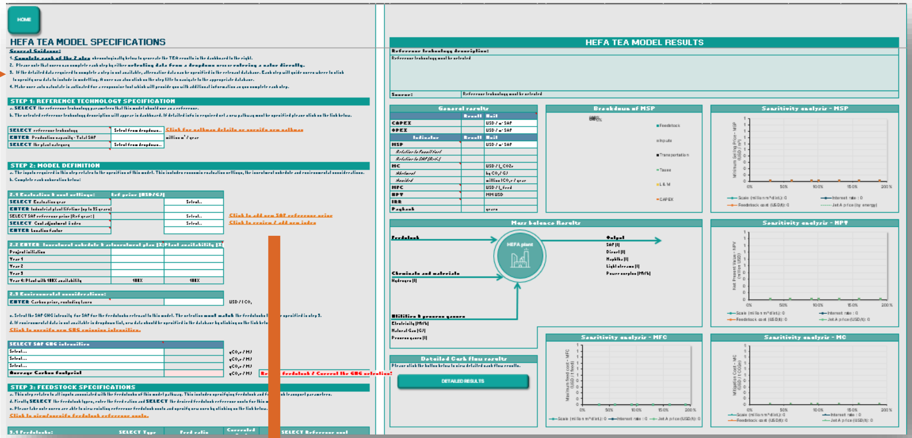
- Hydroprocessed Esters and Fatty Acids (HEFA)
- Fischer Tropsch (FT)
- Alcohol-to-Jet (ATJ) – Standalone
- Alcohol-to-Jet (ATJ) – Integrated

How does the tool look like?

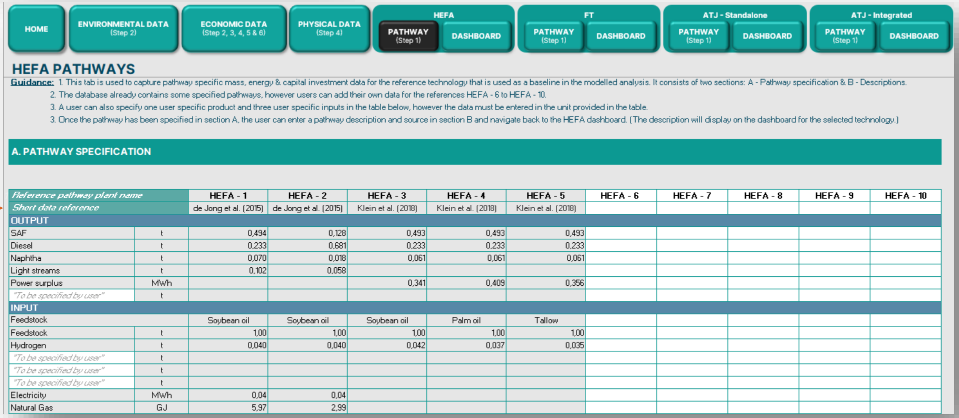
1. Home Page of the Tool



2. Pathway-specific Dashboard



3. Background database



7 Modelling Steps

1 REFERENCE TECHNOLOGY SPECIFICATION

2 MODEL DEFINITION

2.1 Evaluation & cost setting
2.2 Investment schedule & availability
2.3 Environmental considerations

3 FEEDSTOCK SPECIFICATIONS

3.1 Feedstocks
3.2 Feedstock transport

4 PRODUCT SPECIFICATIONS

4.1 Physical data properties
4.2 Main product
4.3 Other products

5 UTILITY & CHEMICAL INPUT SPECIFICATIONS

6 USER SPECIFIC INPUTS & PRODUCTS

6.1 Other product output
6.2 Chemical / Material / Utility inputs

7 ECONOMIC ASSUMPTIONS

7.1 Financing assumptions
7.2 Taxation
7.3 Investment parameters
7.4 Depreciation
7.5 FCI attributed to other expenses

What do I get out of it?

Net Present Value (NPV), million USD

The NPV is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. NPV is used in capital budgeting and investment planning to analyse a project's profitability.

Minimum Selling Price (MSP), USD/m^3

The MSP is the minimum price at which SAF production becomes profitable, calculated at the facility gate without taxes. Costs are allocated to SAF, and other products based on market values. The MSP of SAF is compared to fossil kerosene (Jet A) prices and reference SAF costs from literature or market, based on energy content.

Mitigation Costs (MC), USD/tCO_2eq

The MC is the price per ton of avoided CO_2 needed for SAF production to be profitable (NPV is zero). It is calculated using the price difference between SAF and fossil kerosene and total carbon abatement, based on CORSIA methodology. Annual avoided emissions are estimated from production scale and SAF's carbon reduction.

Maximum Feed Cost (MFC), USD/t_{feed}

The MFC indicates the maximum acquisition cost of the feedstock for a zero NPV, assuming SAF parity to fossil kerosene on an energy basis. A negative value for MFC means that the feedstock would need subsidies.

Internal Return Rate (IRR), %

The IRR is a discount rate that would render the NPV of all cash flows equal to zero in a discounted cash flow analysis. Generally, an IRR higher than MARR (Minimum Attractive Rate of Return) indicates profitable investments.

Payback (PB), years & sensitivity analysis

The PB refers to the amount of time it takes to recover the cost of an investment. Furthermore, the tool automatically performs a sensitive analysis of the indicators, comprising parameters such as income tax rate, production scale, MARR, feedstock cost, and fossil kerosene (Jet A) price.

The TEA tool does not cover…

Environmental Assessment

Carbon abatement costs are calculated to determine mitigation costs, offering a preliminary understanding of potential policy impacts in this area. Accompanying environmental assessments, e.g., by applying RSB's GHG Tool, is recommended.

In-depth Process Assessment

The tool assesses the feasibility and cost-effectiveness of new SAF pathways, identifies cost drivers, and supports decision-making. Once a promising path is determined, in-depth economic assessments based on full-scale process models shall be conducted before final investment decisions are made.

Plant Revamping & Co-Processing

The cost of new SAF production plants, e.g., CAPEX and OPEX, can be estimated for future newly built SAF plants. Costs for the revamping of existing plants or co-processing are not considered.

SAF Transportation, Blending and Use

The tool's system boundaries are from feedstock to the end of the factory gate. Therefore, costs associated with transport, blending, and the use of SAF are not considered.

Market-Based mechanisms

The tool does not consider market-based mechanisms, such as book-and-claim systems.

Upstream Costs

The tool's system boundaries are from feedstock to the end of the factory gate. Therefore, upstream costs, such as regulatory compliance costs, are not considered.

Overview TEA Tool Demonstration with selected SAF pathways

Data for TEA Tool Demonstrations

1 **Primary data**: information collected directly from first-hand sources (e.g., SAF producers or process developers)

→ Data is specific to the SAF feedstock, processing route, and production location.

2 **Secondary data**: information from existing sources (e.g., like literature, public databases, previous studies).

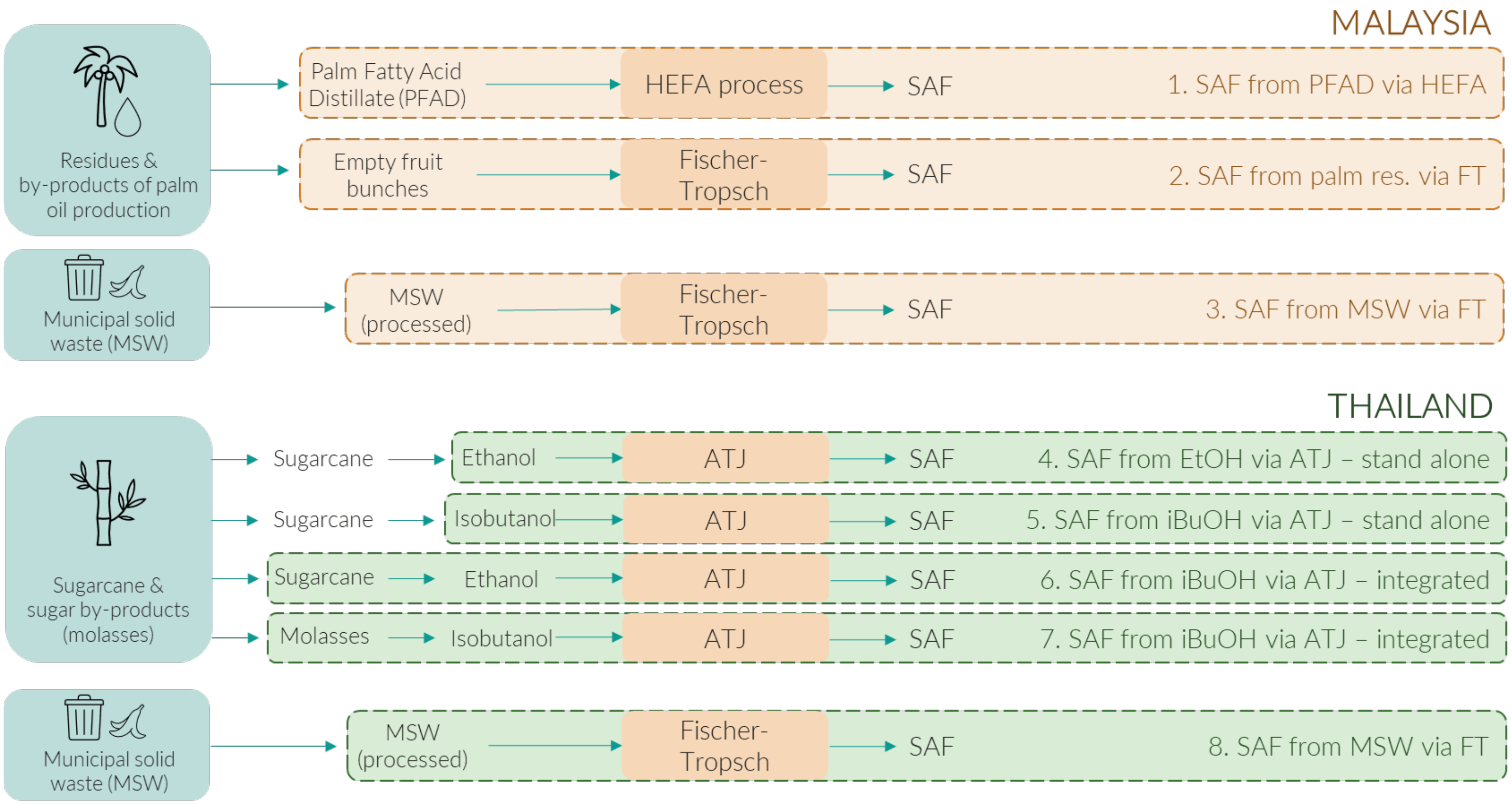
→ Highly specific data often limited

The **TEA tool** is **OPEN** for users to include **country- and pathway-specific data** to facilitate a tailored SAF pathway analysis based on primary data sources.

To demonstrate the applicability of the TEA tool, **SAF production pathways** were selected and modelled using **secondary data.**

TEA Tool Demonstrations

To demonstrate the applicability of the TEA tool, **eight SAF production pathways** were selected and modelled using secondary data (mainly literature, public databases and previous studies)



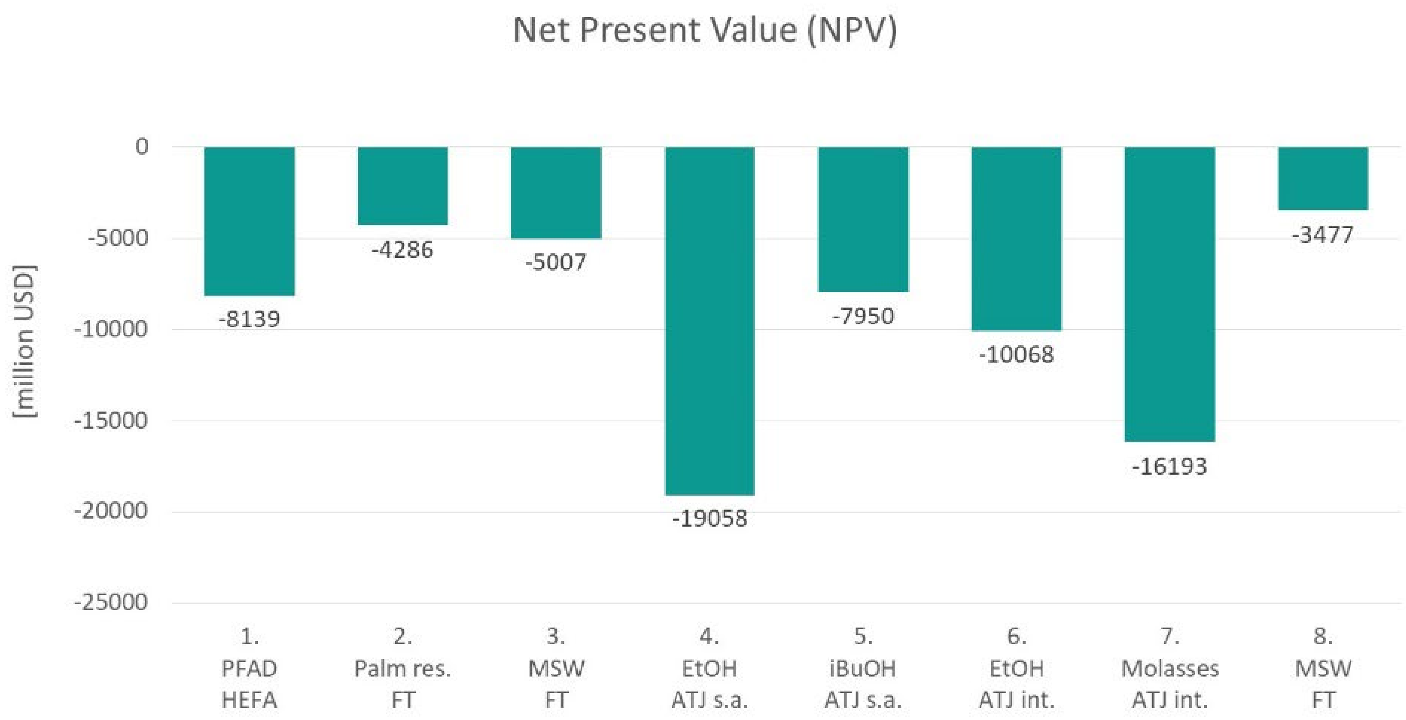
Selected Results from Tool Demonstration

Minimum Selling Price (MSP)

- In all scenarios, the MSP of SAF (388 – 1900 USD/m³) is **still higher than fossil kerosene** (307.2 USD/m³).
- In energy terms, SAF price (at the gate, without taxes) was estimated 38% to 10-fold higher than fossil kerosene.
- 5 of 8 pathways had a **lower or equal MSP** than the SAF reference price.
- **FT-based** pathways (for MSW or palm residues) present the **lower MSP**, while alcohol-based pathway (stand-alone or integrated) presented the higher ones.

MSP: Minimum value for SAF where the net present value (NPV) of the business case is zero, so the price at which SAF production would start being profitable.

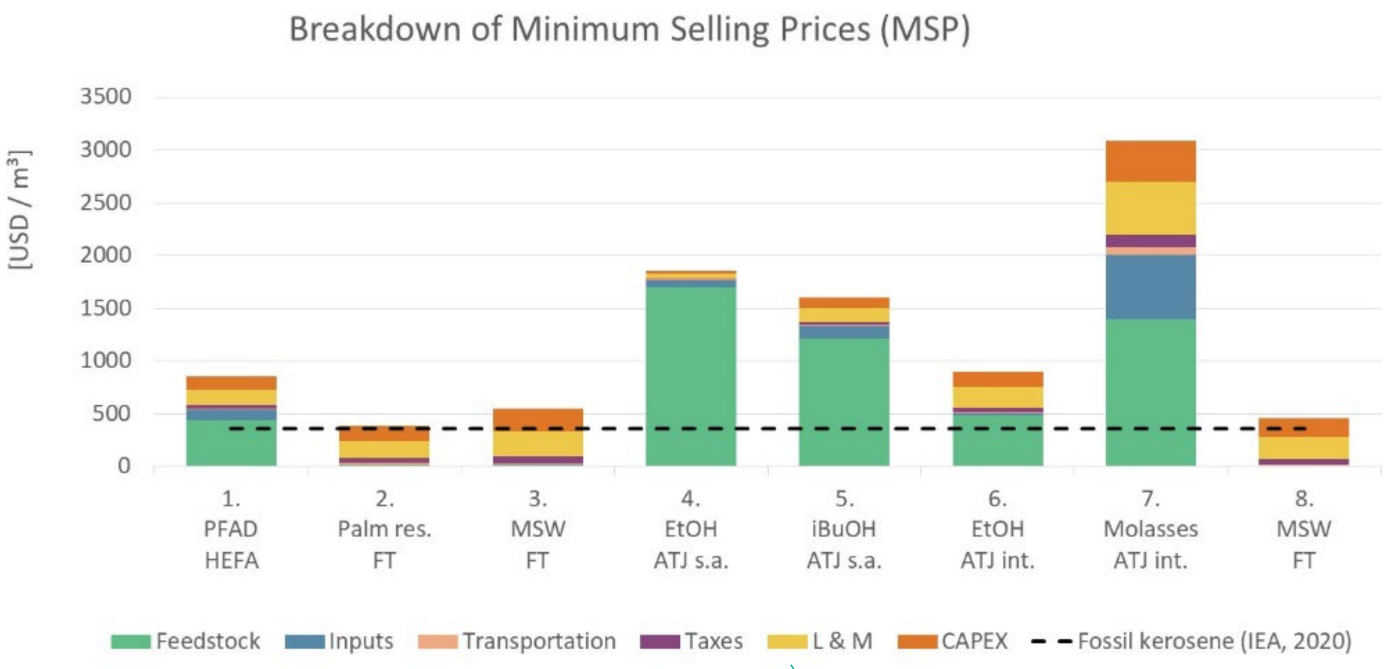
Net Present Value (NPV)



- In all scenarios, a **negative NPV** was determined, due to high differences between the MSP of new pathways and current prices of fossil kerosene.
- More accurate NPV values can be obtained when using **primary input data**.
- A **positive NPV** could be reached by leveraging technical, economic, and political **measures**.

NPV: Difference between the present value of cash inflows and the present value of cash outflows over a period of time. The NPV is used to analyze the profitability of a projected investment or project

Breakdown of Minimum Selling Price (MSP)

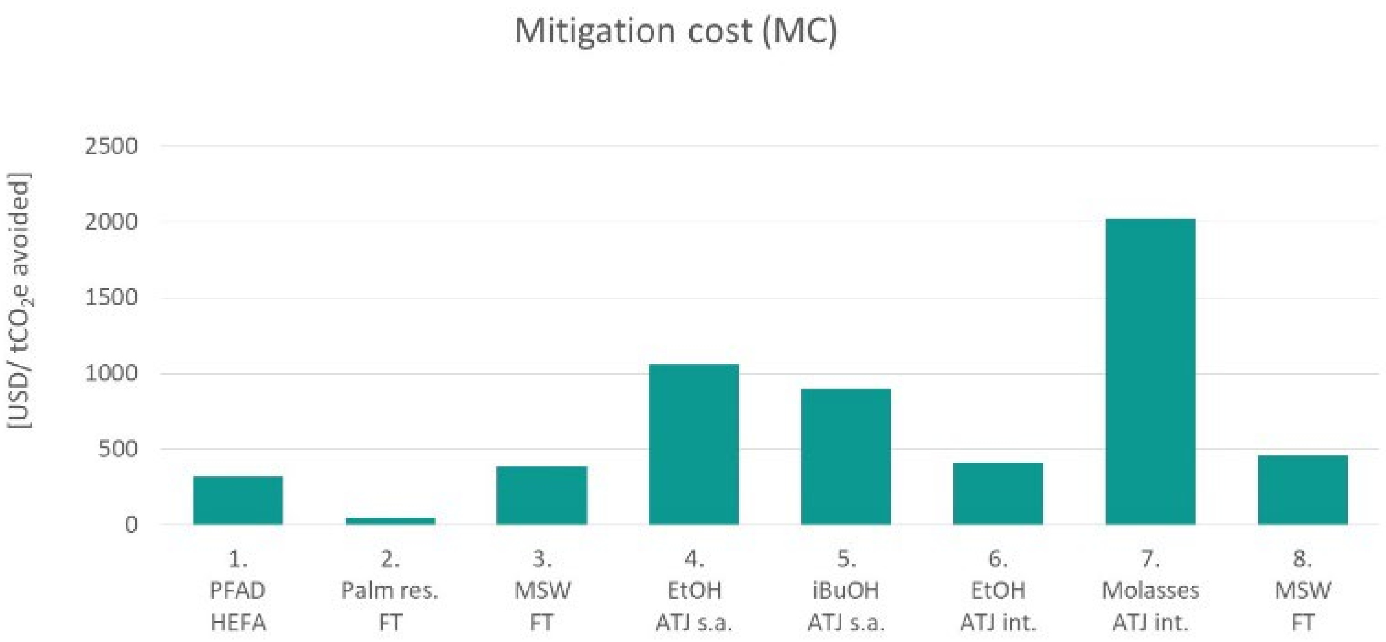


e.g., hydrogen, electricity, natural gas

Labor and maintenance costs, e.g., operation costs, overhead.

- **CAPEX** accounts for ~ 35% of production costs in **FT-based-pathways.**
- **Feedstock costs** account to up to 50% in **HEFA and ATJ**-based pathways.
- **Input costs** (high demand of natural gas) account for ~20% in molasses-iBuOH-ATJ pathway.
- **L&M** have relevant share in all pathways (secondary data).

Mitigation Costs (MC)



- For 5 out of 8 pathways, MC will be lower than **500 USD/tCO_{2e}** avoided.
- The lowest MC were found for the **palm residues-based FT pathway** (50 USD/tCO_{2e} avoided) due to low difference between MSP and fossil kerosene and high avoided carbon content.
- The high MC for MSW-based pathways (around 400 USD/tCO_{2e} avoided) is related to the **non-biogenic carbon (NBC)** assumed for each feedstock.

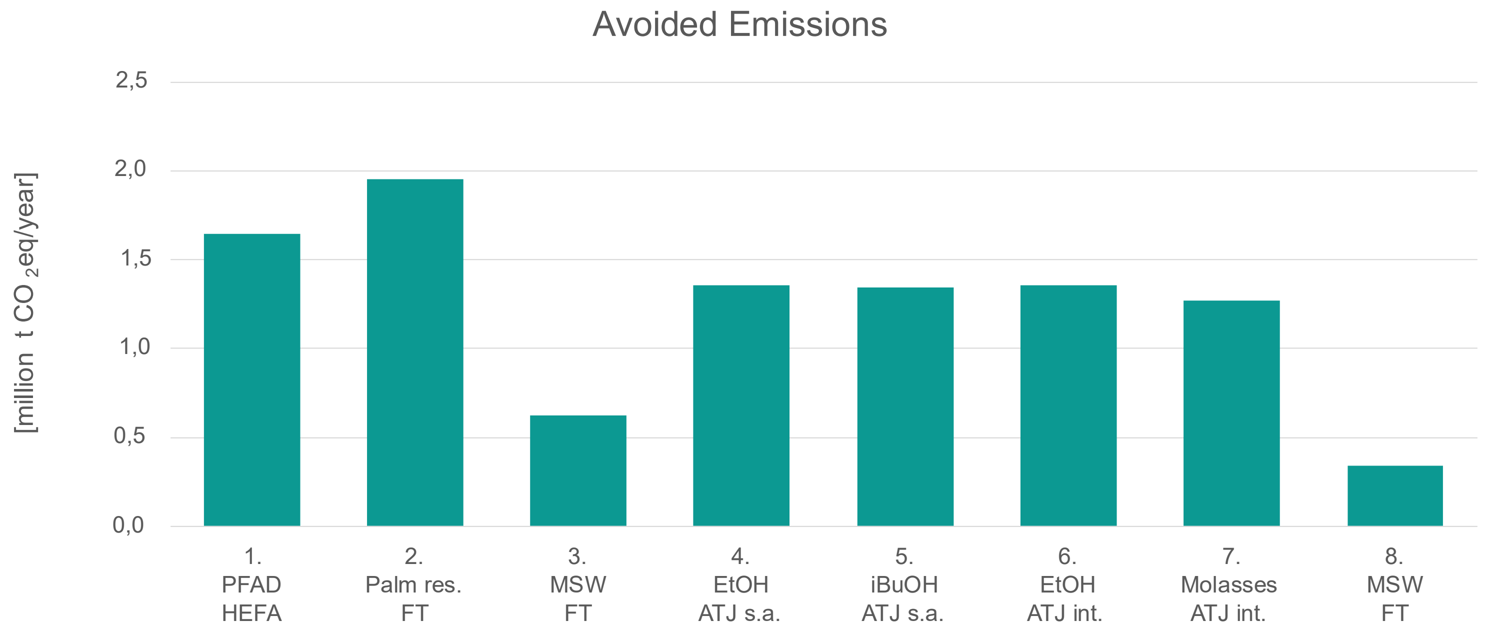
MC: The MC quantifies the costs associated with reducing greenhouse gas (GHG) emissions through the use of SAF compared to conventional jet fuel.

Maximum Feedstock Costs (MFC)

- To reach NPV, all feedstocks would need **subsidies**.
- Even residues-based pathways with low feedstock price (MSW, palm residues) would need subsidies to reach NPV.
- MSW-based scenarios were based on **collection cost assumptions**.
- As feedstock costs play a minor role in the overall MSP in many pathways, high subsidies would be needed to reach NPV.

The MFC indicates the maximum acquisition cost of the feedstock for a zero NPV, assuming that SAF parity to the fossil kerosene, on the energy basis. A negative value for MFC means that the feedstock would need subsidies.

Avoided Emissions



- Assuming a production of 1 million m³ of SAF per year.
- Results are directly linked to the carbon intensity (gCO2e/MJ) assumed for each pathway (CORSIA).
- Agricultural residues have the lowest carbon intensity, which leads to the highest amount of carbon emission avoided.
- Carbon emission credits could be given for MSW-derived SAF.

The annual avoided emissions (million t_{CO2}) were estimated based on the scale production of the industrial plant and the carbon abatement provided by SAF. The carbon abatement was estimated according to the CORSIA methodology, which compares the emission factor of fossil kerosene (89.0 gCO_2/MJ) and the emission factor of SAF on the life cycle basis. The emission factor related to SAF registered in the "Environmental data" sheet.

Conclusions

- The **applicability of the TEA tool** was demonstrated by multiple SAF production pathways using secondary data and by stakeholder validations
- The demonstration and validation phase highlighted, that the TEA tool can be used to:
    - **Identify promising SAF routes** that result in a lower MSP than current SAF reference prices.
    - Determine **main price contributors** per pathway ("economic hotspots").
    - Pinpoint the **impact of individual measures** that could be taken to reach NPV, e.g., subsidies for feedstock prices, mitigation costs etc.

→The TEA tool can help decision-makers identify **promising country- and feedstock-specific SAF pathways** and **leverage** technical, economic, or political **measures** to drive pathway development and ensure future profitability.

→ Stakeholders are interested in seeing **future tool versions** include additional features.

Next: TEA Tool V3

Towards a TEA Tool V3

- Development of an **advanced TEA Tool for SAF** to guide policy-making and investments
- **Timeline:** January 2025 – December 2026
- **Main goals**:
    - Country-specific databases & assessments focussing on Southeast Asia and **Africa**
    - Tailored to guide policy-making and investments
    - Revised selection of key indicators, including economic and environmental indicators
    - Enable direct comparison of pathway models in 1 tool
    - Continous engagement of stakeholders
- **Main expected outcomes**:
    - TEA Tool V3 & Guidances/Tutorials
    - Country-specific assessment reports

Considerations for TEA Tool V3 - Africa

PATHWAYS

Focus on pathways hotspots, e.g. HEFA from UCO, non-edible oilseeds or animal fats

READINESS INDEX

Establish and calculate country-specific readiness index for SAF, including technology, sustainability, policy, infrastructure & feedstocks

STATUS QUO

Analyse latest reports and findings to guide tool development

FEEDSTOCKS

Focus on country-specific feedstock hotspots, e.g. MSW, UCO and forestry residues in South Africa

REGIONAL USE CASES

Develop high-impact country-specific or regional use cases (e.g., SACD, EAC)

Take home messages

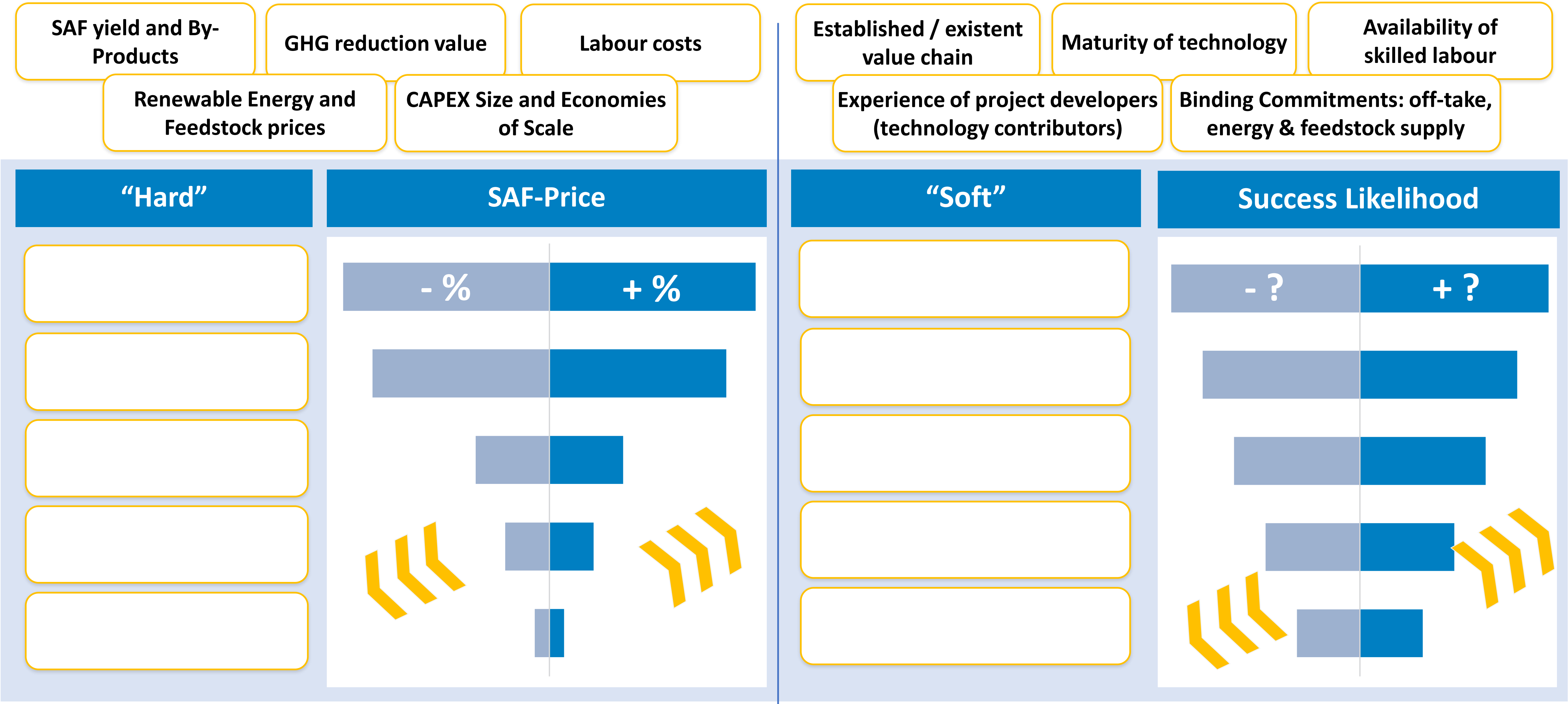
How is a TEA tool developed, advanced and maintained?

1. TEA tool development is a collaborative, **multi-stakeholder effort**.
2. Validation and **user-centered design** are essential to ensure usability.
3. **Data availability** is a critical factor influencing result accuracy.
4. Tailoring tool outputs to **audience needs** enhances usability and decision-making impact.
5. Tool outputs support **deeper assessments** and ongoing improvements.

Questions?

?!

Techno-economic input factors driving the Green Premium



Source: CBR Sustainability Partners 2024

Techno-economic input factors driving the Green Premium

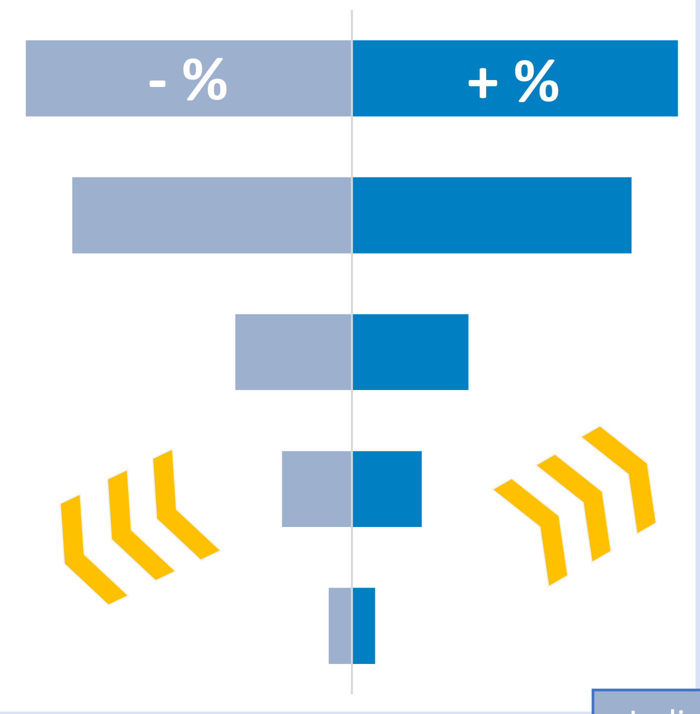
Access to price **competitive feedstocks** and **renewable energy** are one of the most important success factors of SAF business cases.

Soft factors are equally important to reduce **project risk** and enhance the likelihood of matching **expected business case returns**.

"Hard"

- Renewable Energy and Feedstock prices
- GHG reduction value
- CAPEX Size and Economies of Scale
- SAF yield and By-Products
- Labour costs

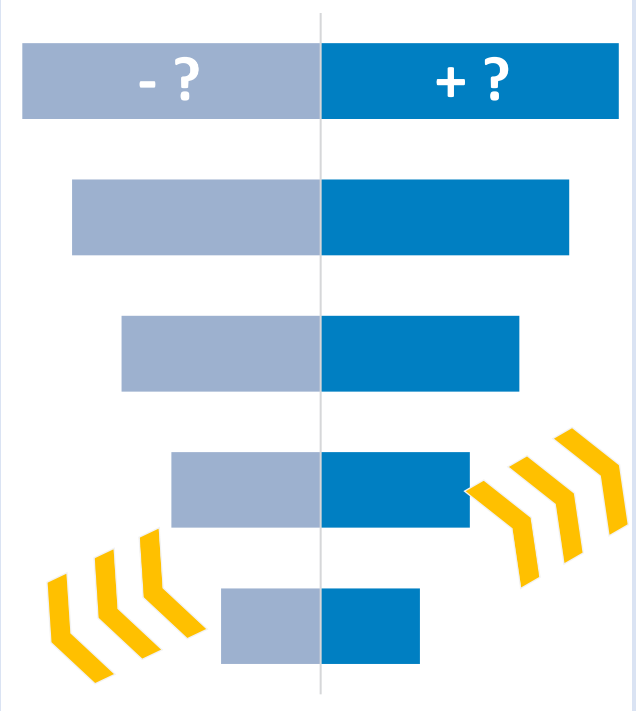
SAF-Price



"Soft"

- Experience of project developers (technology contributors)
- Maturity of technology
- Established / existent value chain
- Binding Commitments: off-take, energy & feedstock supply
- Availability of skilled labour

Success Likelihood



Indicative / Simplified

Note: The factors weigh differently, depending on the timing in the project!

EASA

Source: CBR Sustainability Partners 2024

Excel based, freely available models, tools and studies facilitate a TEA

Freely available, excel based TEA models:

Project SkyPower:

- AtJ and FT: https://project-skypower.org/news-publications/open-source-techno-economic-model-e-saf-production

ASCENT Techno-Economic Analyses (Washington State University):

- ATJ: https://doi.org/10.7273/000001461
- FT: https://doi.org/10.7273/000001459
- HEFA: https://doi.org/10.7273/000001460
- CH: https://doi.org/10.7273/000002564

Software options:

Intelligen SuperPro designer

Microsoft Excel

Sensitivity Analysis

ASPEN Plus

CHEMCAD

DWSIM

Publicly available feedstock studies:

Publicly available interactive PtX tools:

H_2Atlas-Africa

JÜLICH Forschungszentrum

Bundesministerium für Bildung und Forschung

WASCAL West African Science Service Centre on Climate Change and Adapted Land Use

SASSCAL Southern African Science Service Centre for Climate Change and Adaptive Land Management

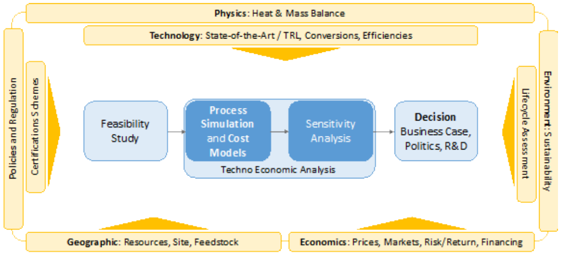
PtX global ATLAS

Global PtX Atlas by Fraunhofer

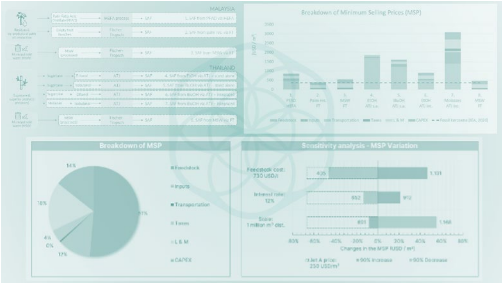
South African Green Hydrogen Atlas

Non-exhaustive

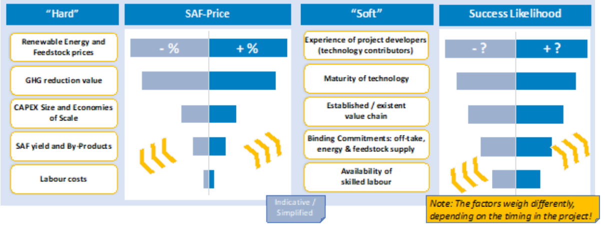
Key take-aways



A TEA consists of a technical and a financial model, delivering a **first estimate**, to support **business case, political or R&D decisions**.



TEA tool development is a **collaborative, multi-stakeholder** effort.
Validation and **user-centered** design are essential to ensure **usability**.



A sensitivity analysis can help identify main drivers and bottle necks. However, **thoughtfully sourced inputs** are a necessity for the reliability of the results.

EASA

Q&A Starters

- Is a TEA the tool adding value to your project at its current stage?
- What data material would you need to feed into a TEA?
- Who could support you gather required information?
- What is your feedback to the TEA tool presented by RSB?
- What needs to be improved to add value to your questions?

Thank you for your attention!

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