BioTheRoS

Collaborative actions to bring novel **BIO**fuels **THE**rmochemical **RO**utes into industrial **S**cale

# Workshop on 'Alternative and Renewable Fuels'

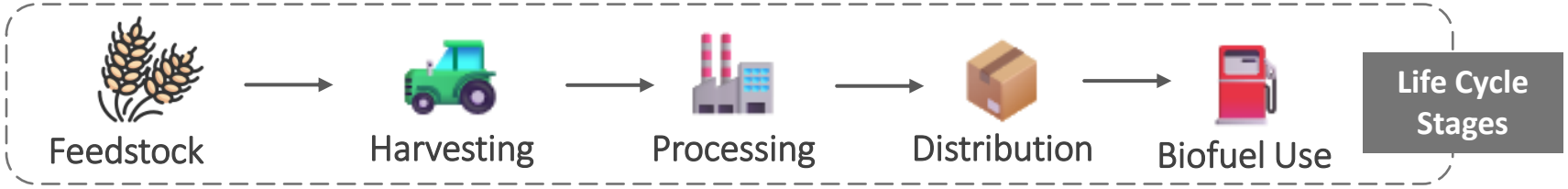
## *"Innovative Tools for Sustainable Decision-Making in Biofuels"*

Angeliki Sagani, CERTH

CERTH
CENTRE FOR RESEARCH & TECHNOLOGY HELLAS

Motor Oil (Hellas) Corinth Refineries S.A | 23rd October 2025

# Why Sustainability Assessment for Biofuels?




## Sustainability Assessment: Ensuring Real Impact

- Measures environmental, economic and social performance
- Confirms biofuels delivers true sustainability gains
- Required for policy compliance and market credibility

## The Real-World Challenge: Complex Trade-offs

- Low carbon does not always mean low impact
- Cost, emissions and social factors often conflict
- Industrial decisions often need a structured comparison framework

## The Solution: Integrating MCDCA

- MCDA helps balance competing sustainability criteria
- Translates assessments into clear, evidence-based rankings
- Supports transparent, participatory decision-making

Sustainability Assessment tells us how sustainable are biofuels from a life cycle perspective – MCDA helps us decide which pathways are truly worth pursuing



BioTheRoS

# Life Cycle Sustainability Assessment (LCSA)

## Complete Framework:

*A holistic approach integrating environmental, economic, and social impacts across the full life cycle*

### 1. Goal & Scope Definition

- Define system boundaries & functional unit
- Align with ISO 14040/14044 standards
- Establish assessment objectives
- Identify key stakeholders

### 2. Life Cycle Inventory

- Compile inventory data across life cycle stages
- Map material and energy flows
- Document emissions, waste and by-products
- Ensure data quality and completeness

### 3. Life Cycle Assessment

- Evaluate environmental impacts (e.g., GHG emissions, fossil energy use)
- Analyze resource consumption
- Identify environmental hotspots

### 4. Life Cycle Costing

- Evaluate economic performance
- Analyze CAPEX & OPEX
- Identify cost drivers across life cycle
- Assess risks and opportunities

### 5. Social Life Cycle Assessment

- Measure social performance indicators
- Analyze health and safety aspects
- Evaluate social impacts on stakeholders

### 6. Interpretation

- Identify trade-offs & synergies
- Create sustainability dashboard
- Develop actionable recommendations

# Multi-Criteria Decision Analysis & Innovation

## What is MCDA

*Foundation on structure decisions*

Multi-Criteria Decision Analysis (MCDA) is a structured framework for evaluating and comparing alternatives across multiple, often conflicting criteria, balancing environmental, economic & social impacts. *Key capabilities: Trade off analysis; Transparent weighting; Stakeholder engagement, Risk assessment*

## What is Innovation in MCDA

*Advanced decision tools*

Involves the use of advanced methods, tools, and technologies to enhance decision-making, improving accuracy, transparency, inclusiveness, and sustainability, and enabling smarter, data-driven, and more adaptive solutions.

## Why is innovation essential

*Addressing critical gaps in traditional approaches*

### Traditional Limitations

- **Single factor focus**
  Cost prioritized, neglecting social or environmental impacts
- **Short-term thinking**
  Immediate gains prioritized over long-term sustainability

### Data-driven Adaption

- **Emerging data sources**
  IoT sensors, real-time monitoring requires digital tools
- **Complex datasets**
  Multi-dimensional information

### Enhanced Strategic Value

- **AI/ML integration**
  Machine learning enhanced prediction accuracy
- **Sustainability metrics**
  Comprehensive KPIs drive long-term strategic value

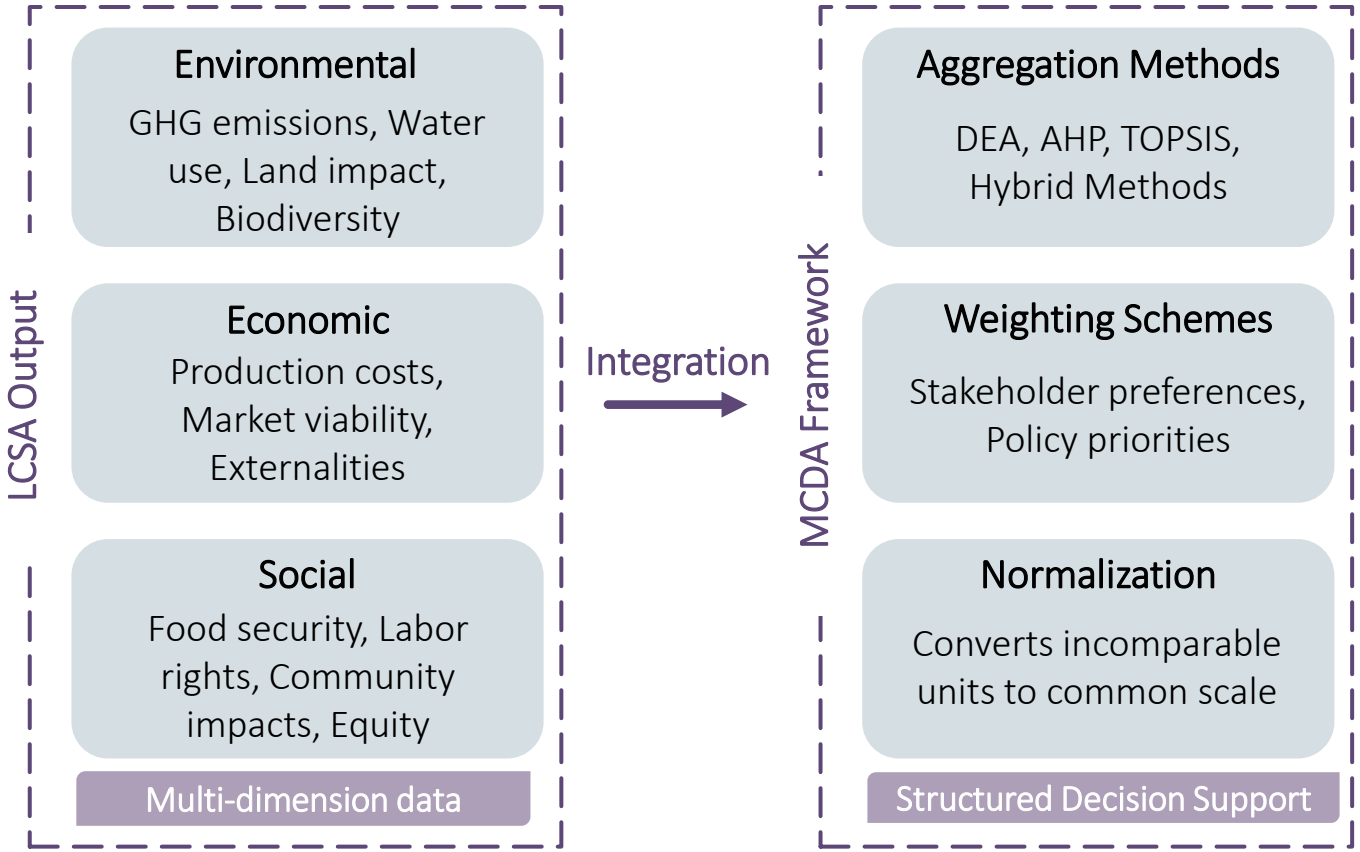


BioTheRoS

# Integrating LCSA with MCDA for Biofuels

## The Decision-Making Challenge

LCSA generates multi-dimensional sustainability data (environmental, economic, social), but policymakers and stakeholders need clear guidance: *Which biofuel pathway is best? How do we trade off conflicting objectives?*




### TOPSIS

Ranks alternatives by distance to ideal and anti-ideal solutions. Common in biofuel sustainability assessment.

Distance-based ranking

### DEA

Identifies efficient biofuel pathways on the sustainability frontier.

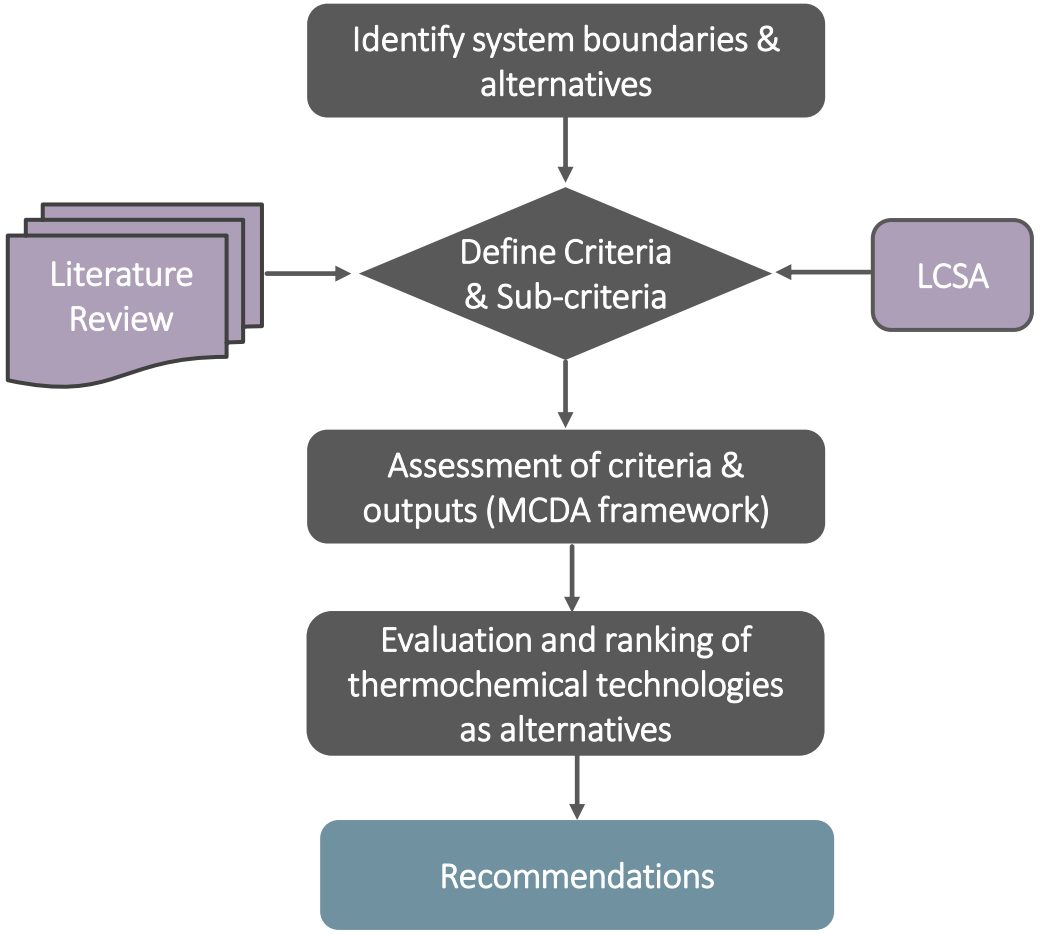
Efficiency frontier



BioTheRoS

# 6-Step LCSA-MCDA Integration Framework

1. **Goal & Scope** — The selection of the most optimal thermochemical technology
2. **Conduct LCSA** — Execute Environmental LCA, LCC & Social LCA
3. **Define Criteria** — Transform LCSA outputs into environmental, economic & social criteria
4. **Stakeholder weighting** — Engage stakeholders using relevant weights
5. **Apply MCDA** — Run MCDA method to generate rankings
6. **Sensitivity Analysis** — Test robustness by varying weights and assumptions



# How MCDA Enhances Life Cycle Sustainability

## Why LCSA-MCDA Integration is Essential for Biofuels ?

### 1. Handles Trade-offs Explicitly

MCDA provides transparent methods to balance competing criteria (e.g., low GHG emissions vs. high production costs). Stakeholders can see how different weightings affect outcomes.

### 2. Incorporates Stakeholder Preferences

Different stakeholders prioritize differently. MCDA allows policymakers, industry, and communities to weight criteria according to values, enabling participatory decision-making.

### 3. Enables Scenario Analysis

Test sensitivity to changing conditions (e.g., carbon pricing, feedstock availability, technology improvements). Identify robust biofuel pathways under uncertainty.

### 4. Supports Policy Decisions

Provides ranking or classification of biofuel alternatives based on comprehensive sustainability performance, guiding R&D priorities, subsidy allocation, and regulatory standards.

# Emerging Role of AI and ML in Biofuels Sustainability

## Transforming Biofuel LCA Through Intelligence

Artificial Intelligence (AI) & Machine Learning (ML) boost efficiency and reliability across the biofuel life cycle - from feedstock to use phase - revolutionizing LCSA through industrial digitalization.

## ML Applications Across Biofuel Life Cycle Stages

ML applications span from initial feedstock assessment through production optimization to final consumption analysis, enabling data-driven decision-making at every stage of the biofuel value chain.

1. **Soil & Feedstock** — Yield prediction; Crop selection; Resource assessment
2. **Biofuel Production** — Process optimization; Efficiency enhancement; Quality control
3. **Biofuel Use** — Real-time monitoring; Impact prediction; Technology performance

### ML in LCSA Assessment

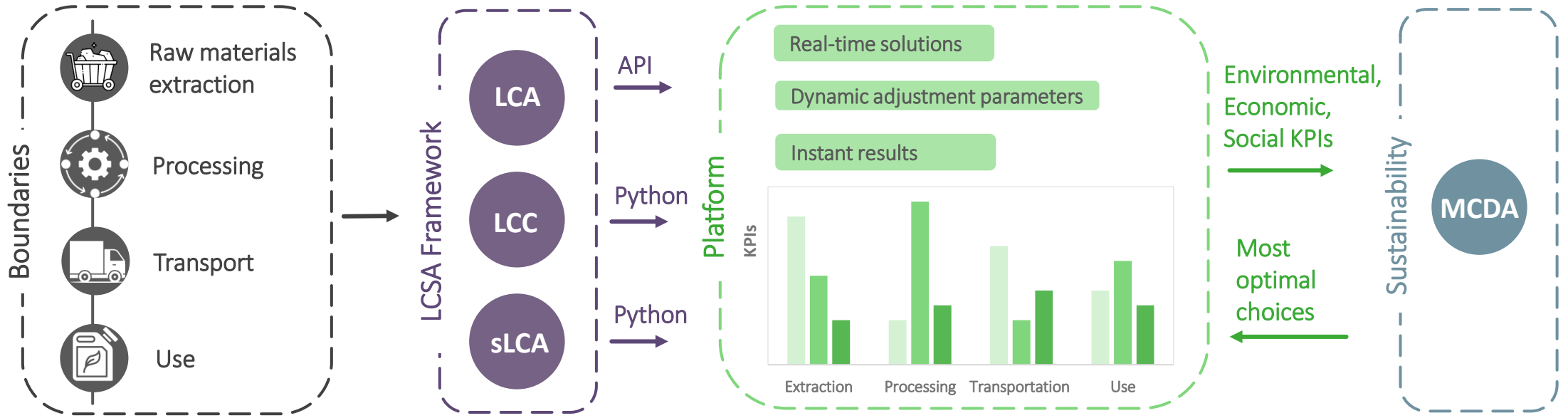
- Predictive Modelling
- Uncertainty reduction
- Scenario forecasting
- Pattern recognition

*** Most utilized ML model: Artificial Neural Network (ANN)*

# Our Sustainability Tools

## Real-Time Simulations Platform

Enables Life Cycle Assessment, Life Cycle Costing, Social Life Cyle Assessment, and Multi-Criteria Decision Analysis in real-time




Benefits

- Simplifies complex LCA, LCC & sLCA processes with user-friendly tools
- Faster, data-driven decisions for environmental, economic, and social impact
- Optimized cost and resource in LCSA analysis



BioTheRoS

# Intelligent LCA, LCC & MCDA Dashboards

Intelligent decision-making tool that empowers industries to assess sustainability, optimize costs, and choose the most eco-efficient production pathways.

## LCA Dashboard

API integration with commercial LCA tools for high-quality environmental assessments

**Assess Environmental Impact**
Evaluate environmental KPIs (e.g., GHG emissions, fossil energy use

**Customize Input Parameters**
e.g., Modify energy mix composition (renewable vs. non-renewable)

**Visual Analysis**
Interactive graphs for optimization insights

## LCC Dashboard

The dashboard communicates with custom LCC tools, enabling reliable cost evaluations

**Assess Economic Viability**
Analyze CAPEX, operational costs and biofuel production costs

**Customize Input Parameters**
Adjust equipment costs, OPEX and discount rate for tailored assessments

**Visual Analysis**
Interactive graphs for clear insights into economic viability

## MCDA Dashboard

The dashboard integrates with MCDM tools, providing robust sustainability assessments

**Evaluate Multiple Criteria**
Assess environmental, economic, and social factors to select the best pathway

**Customize Input Parameters**
Adjust the importance of each criterion and sub-criterion for tailored LCSA

**Visual Analysis**
View interactive graphs with rankings and scores for easy comparison

## Comparison Dashboard

*Analyze LCA and LCC results side-by-side to assess environmental and economic trade-offs*



BioTheRoS

# Strategic Impact & Business Value

## How Can Industries Use the Results?

### TEC Innovation

Customize and assess LCA, LCC, sLCA, and MCDA models for improved sustainability and efficiency.

### Operational Improvements

Streamline supply chains using real-time data to minimize resource use and environmental impact

## Unlocking Strategic Value & Sustainable Growth

- **Scalable Across Industries:**
  Adaptable tools for manufacturing, energy, and infrastructure sectors.
- **Business Impact:**
  Achieve real-time sustainability tracking, cost savings, and stronger compliance.
- **Future-Ready Innovation:**
  Simplified tools drive data-based decisions and sustainable growth.



BioTheRoS

# Thank you!

Angeliki Sagani, CERTH
Research Engineer
sagani@certh.gr

Dr. Dimitrios Kourkoumpas, CERTH
Senior Research Engineer
kourkoumpas@certh.gr

CERTH
CENTRE FOR
RESEARCH & TECHNOLOGY
HELLAS



BioTheRoS