

Sustainability Metrics Methodology and How it can be used for Biofuels

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Industrial process sustainability and applicable metrics

- Sustainability of what? - - System Classification
- System Identification
- How to Measure Progress? - - Metrics Classification
- Identification of Metrics
- Hierarchical Analysis for Process Sustainability
- Metrics Aggregation

I: Global Systems
(e.g. global CO2 budgeting)



Sustainable Systems Classification

II: Regional Systems
(e.g. watersheds, land planning)



III: Business or Institutional Systems
(e.g. waste exchange networks, eco-industrial park)



IV: Sustainable Technologies
(e.g. green chemistry & engineering)

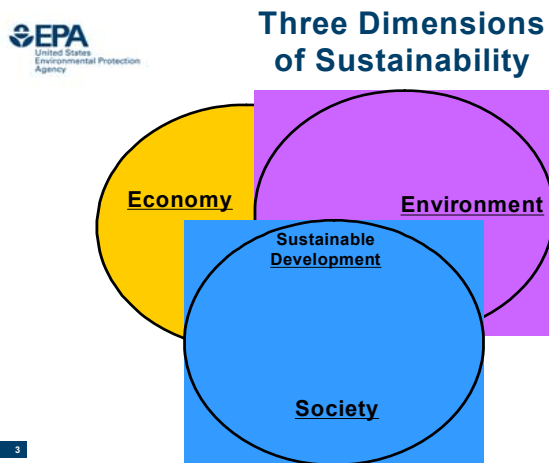


*System definition
addresses the question:
Sustainability of what?*

4 Categories of Sustainable Systems

President's Council for Sustainable Development

- Sustainable development is an evolving process that improves the economy, the environment, and society for the benefit of current and future generations.



The Road To Sustainability

Impact Assessment
Risk Assessment
Risk Management

Benign
by Design

WASTE
MINIMIZATION



Computer
Modeling

Green
Chemistry
CLEAN CATALYSTS

SEPARATION
TECHNOLOGIES

Clean
Products

Life Cycle
Assessment
(LCA)

Ecosystems
Modeling

CLEAN ENERGY
Renewable Sources
Electrochemistry
Solar, Wind, Biomass

Systems
Analysis

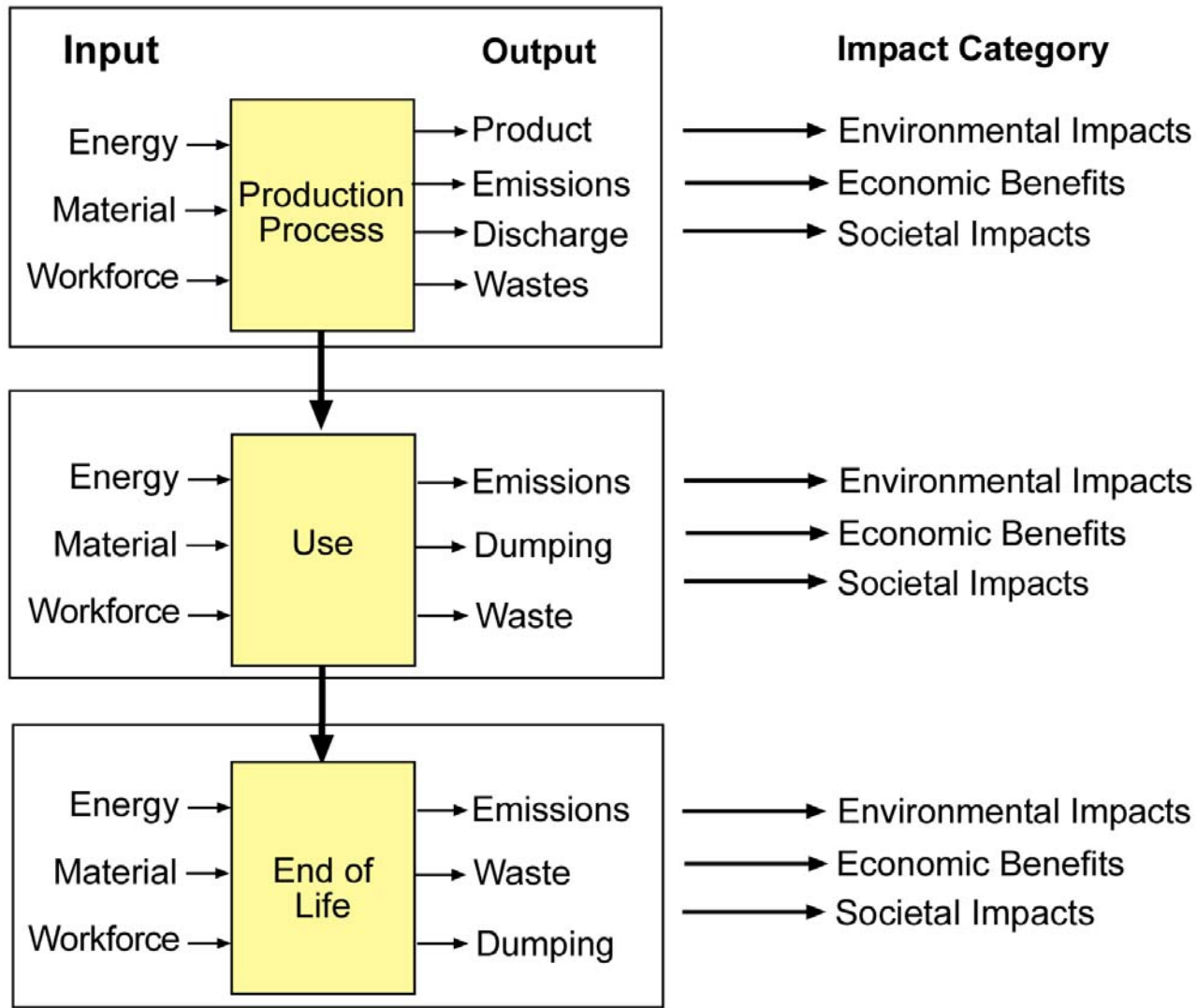
Credit Trading
Design

Watershed
Protection

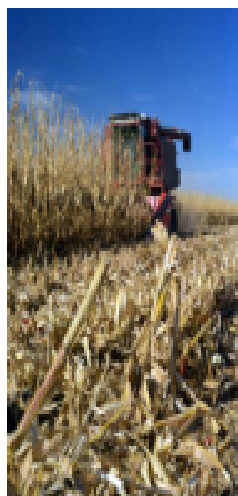
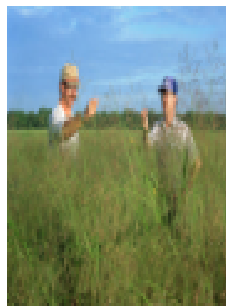
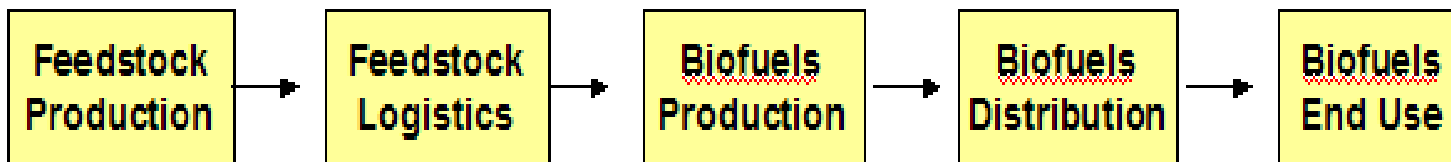
Industrial
Ecology

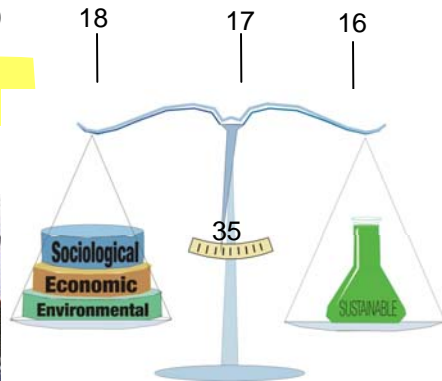
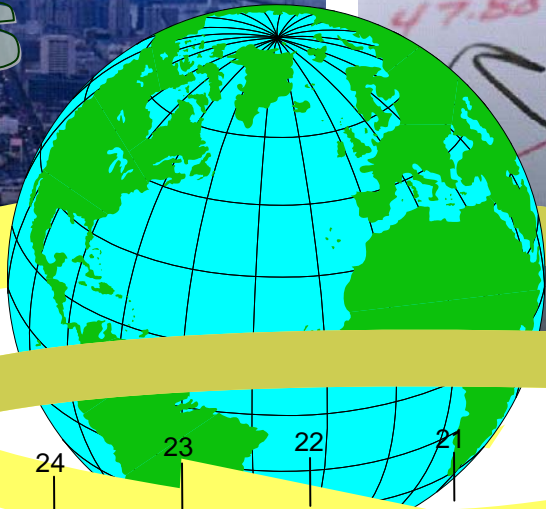
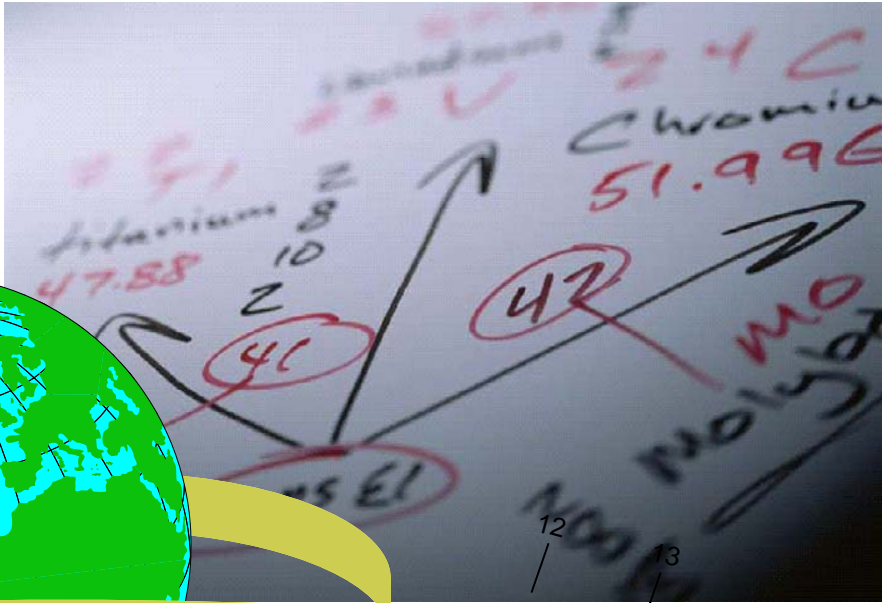


Environmental, Economic, and Societal Impacts from a Life Cycle Basis



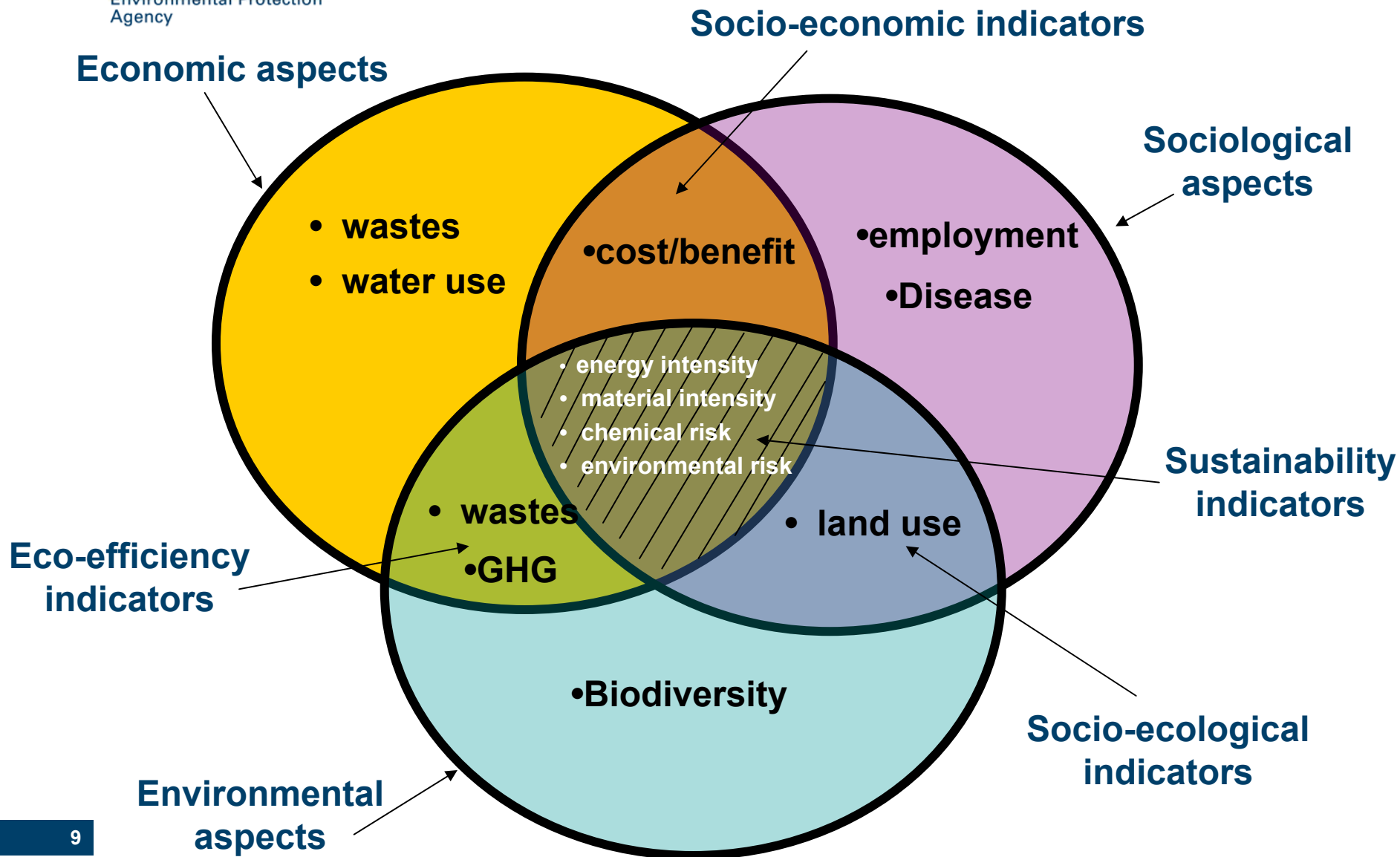
Biofuels across the supply chain





MEASURABILITY

Hierarchical Metrics System



Metrics for Sustainability

- Sustainability metrics (or indicators) need to be chosen for each problem system.

Indicators can be grouped into three categories and **Prioritized:**

- | | |
|------------|---|
| Group I: | One dimensional: economic, ecological, societal |
| Group II: | Two dimensional: socio-economic, eco-efficiency, and socio-ecological |
| Group III: | Three dimensional: sustainability |

Sustainability Metrics for Biofuels

Metrics

(A possible list)

- **Life cycle energy efficiency** (energy output/energy input), 3D
- **GHG emission/gal**, 2D
- **Fossil fuel use (MJ/gal)** (energy out/fossil energy input), 3D
- **Pollutants emissions (T/d)**, 3D
- **Air pollutants emitted (T/d)**, 3D
- **Water Use**, 2D or 1D (depending on location)

Note: In prioritizing, two 3D metrics: materials use, and potential environmental impact have been judged as less important

Hierarchical Analysis

- **Select the metrics to be used**
- **Classify them in 3D, 2D, and 1D metrics**
- **Prioritize metrics in each category (Pareto Chart, sensitivity of metrics to changes in system properties)**
- **Compute the values of the prioritized metrics for a given system intervention in sequential order (3D, 2D, 1D)**
- **“Strong Sustainability”**: Examine for sustainability improvement against the definition that when at least one metric improves, the other metrics do not decline (Pareto optimality)
- **“Weak Sustainability” (Real World)**: Compute Aggregate Metric, find conditions that improve Aggregate Metric to targeted values (process development)

Consolidation of Metrics

For metrics m_1, m_2, \dots , applied to a base case X and a new case Y, we introduce the composite measure D as

$$D = \left\{ \prod_i^n (y_i/x_i)^{c_i} \right\}^{1/n}$$

Where c_i is the weighting factor ($0 < c_i$) for metric i

y_i is the value of metric i for Y

x_i is the value of metric i for X

and n is the number of metrics used.

- Idea based on geometric mean of the ratios (dimensionless) of the values of the metrics between the two states being representative of the difference between the two states X and Y.



Environmental Fingerprints of alternate Curing Processes

Shonnard, Kirchner, and Saling, ES&T: 2003, 37, 5340-5348

Process

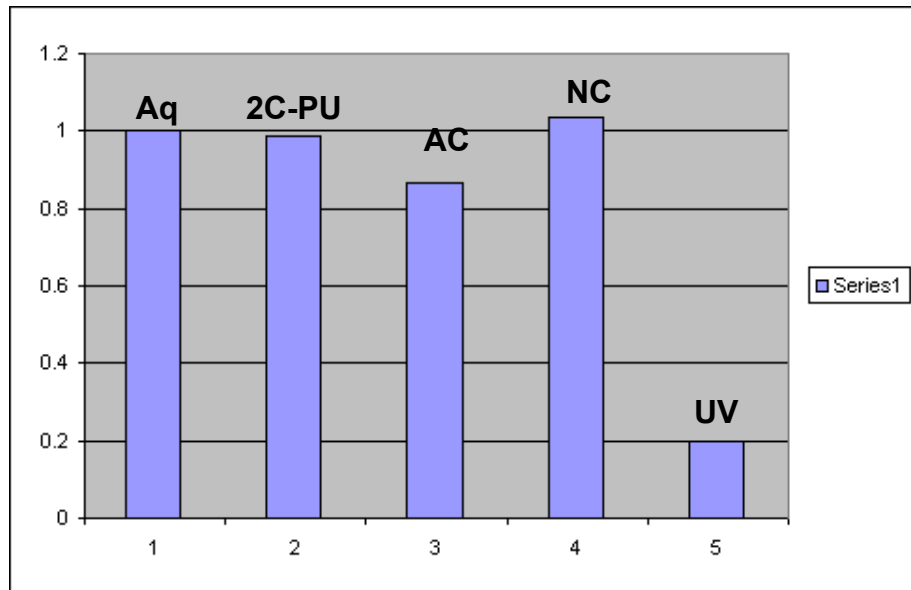
Aggregated metric, D

Metrics used:

**Aqueous coating:
2 C-PU Coating
AC-Coating
NC-Coating
UV-Coating**

**1.0
0.987
0.868
1.034
0.196**

**energy consumption, raw
matl consumption, risk
potential, toxicity potential,
emissions into media**



Sustainability Analysis of Biodiesels: Mata, Martins, Costa, and Sikdar (in press), 2009

Indicator	PD	TB	PB	SUB	RME	REE	SB	JB	Microal gae
Energy intensity (MJ/kg fuel)	6.7	22.9	35.6	38.4	39.2	51.8	101.5	34.6	-
LCEE: 1D	6.3	1.7	1.3	1,0	1.9	1.9	0.4	21.3	-
FER: 1D	6.3	1.7	1.3	1,0	1.4	1.1	0.4	1.7	-
Carbon Footprint (kg CO ₂ -eq/kg fuel): 2D	4.3	4.8	1.6	1.9	2.1	2.9	2.9	-	-
Land use intensity (m ² .yr /kg biodiesel)	-	-	2.4	12	13.2	13.2	20.3	17.39	0.9-0.2

D

1

1.305

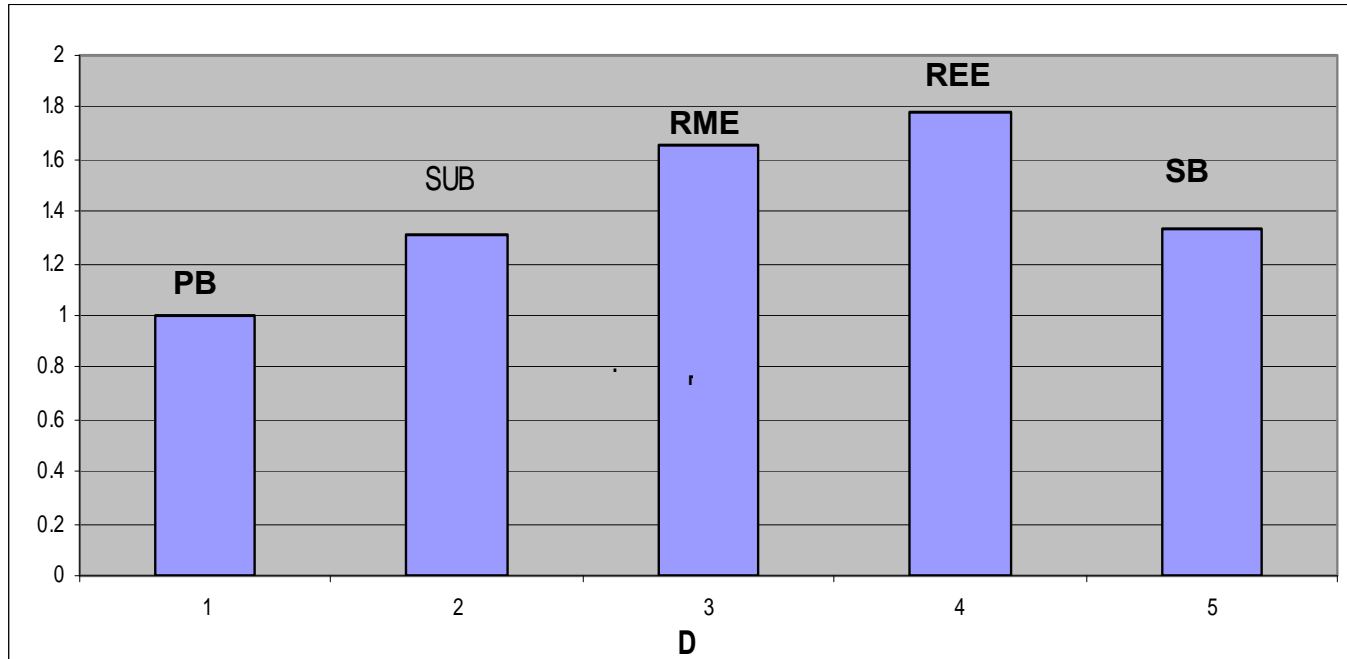
1.657

1.781

1.328

PD: petroleum diesel; TD: tallow biodiesel; PB: palm biodiesel; SUB: sunflower biodiesel; RME: rapeseed methyl ester; REE: Rapeseed ethyl ester; SB: Soybean biodiesel; JB: Jatropha biodiesel

Note: Two other 3d metrics were considered: potential environmental impact and material used but not used because of lack of relative Significance. Similarly, water use (2D) was also not used.



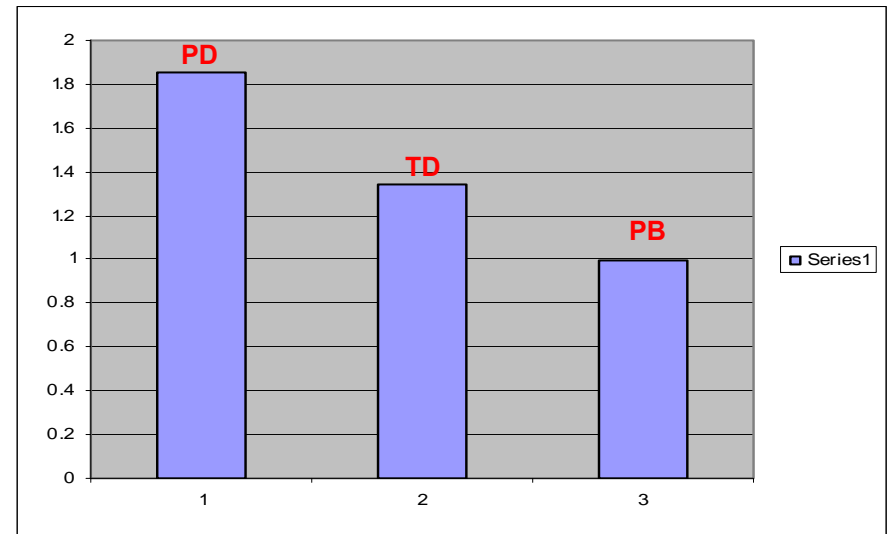
Sustianbility analysis of Biodiesels

Comparison among PD, TD, and PB

Energy Int.	6.7	22.9	35.6
LCEE	6.3	1.7	1.3
FER	6.3	1.7	1.3
CO2 sig.	4.3	4.8	1.6
	PD	TD	PB

D	1.856	1.347	1
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LCEE = life cycle energy efficiency = energy output/input
 FER = fossil energy ratio = fuel energy output /fossil energy input



PD: petroleum diesel; TD: tallow biodiesel
 PB: palm oil biodiesel

Hierarchical Analysis

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NRMRL

U.S. Environmental F

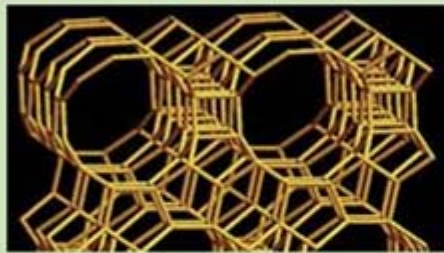


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