Contabilidad Ambiental Usando eMergía: Una Herramienta para Valorar Bioenergéticos

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Objetivo

- Ilustrar el método eMergético como una herramienta para valorar bioenergéticos
- Se ilustrará con un estudio de caso determinando la sustentabilidad de sistemas agroforestales y agroindustriales de pequeñas comunidades usando indicadores eMergéticos y financieros

VALORACIÓN ECÓNOMICA

- ✓EL CONCEPTO DE VALOR ECONÓMICO REGULADO POR LA OFERTA Y LA DEMANDA / VALOR RECEPTOR

- ✓GENERALMENTE NO INCLUYE LAS EXTERNALIDADES

DIFICULTADES PARA LA VALORACIÓN AMBIENTAL

- INEXISTENCIA DE MERCADO
- INDISPONIBILIDAD DE DATOS
- LIMITANTES DE TIEMPO
- ALTO COSTO DE LA INFORMACIÓN

Métodos

- Análisis eMergéticos
  - Tasa de inversión
  - Tasa de carga ambiental

- Análisis financieros
  - Tasa neta utilidad

Ejemplo de un Diagrama de Sistemas

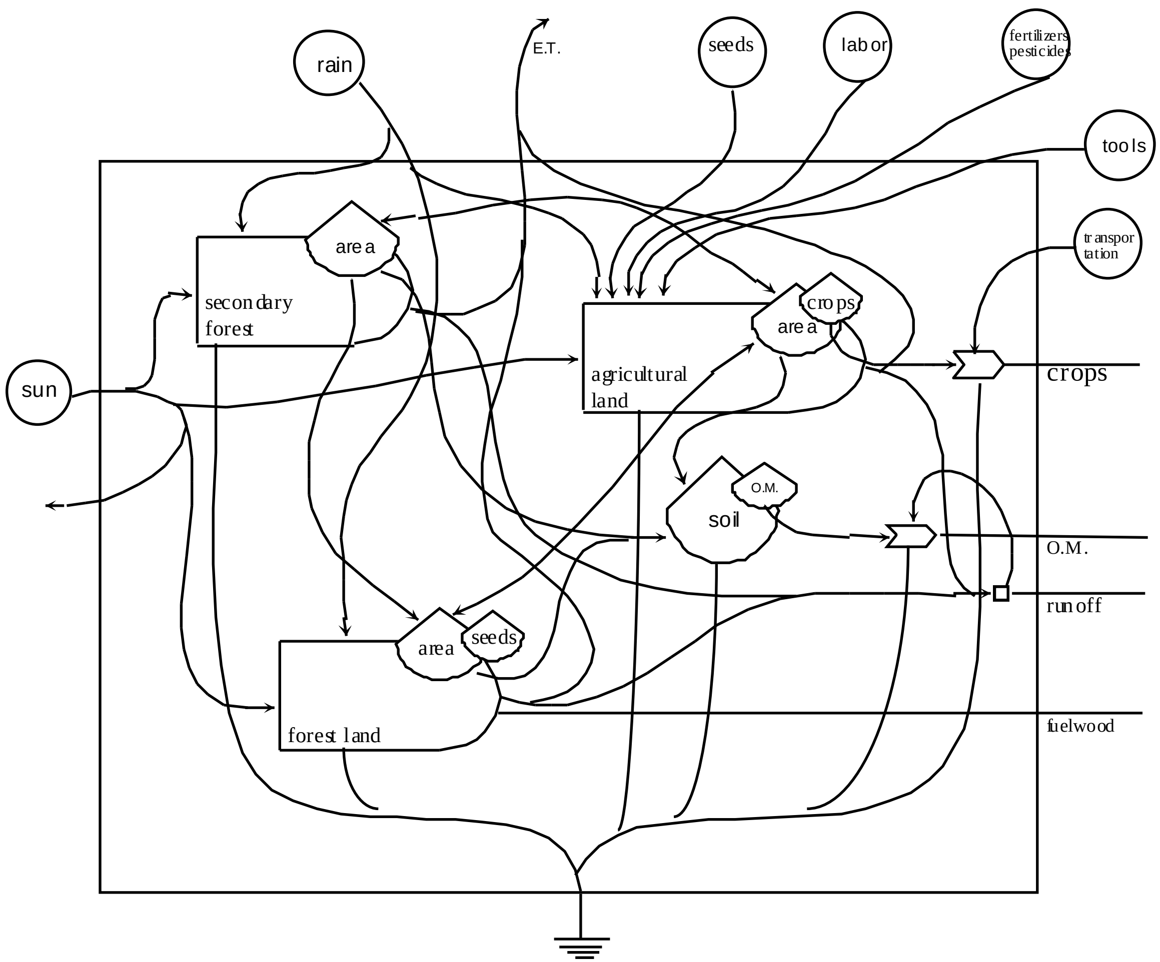


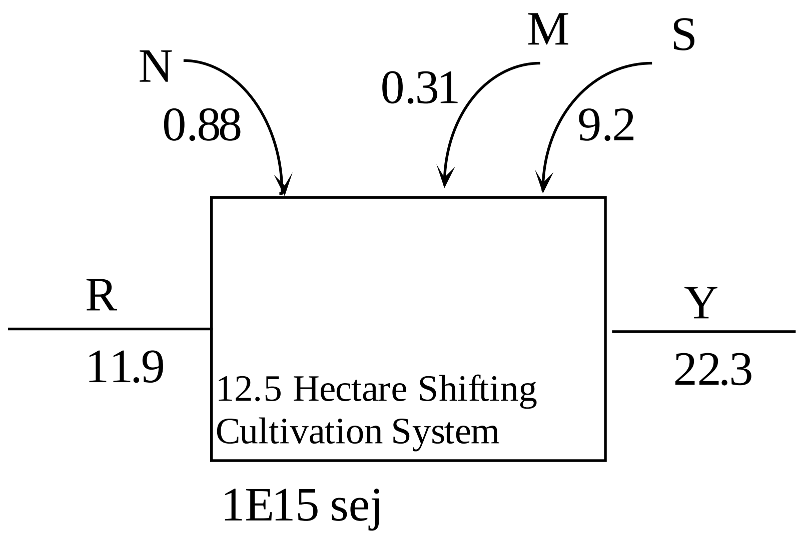
Figure 3-35. Shifting Cultivation System Diagram.

Ejemplo de una Tabla de Evaluación eMergética

Table 1. Emergy Evaluation of Shifting Cultivation System.

Note	Item	Raw Units (units/yr)	Trans-formity (sej/unit)	Solar Emergy 1E+15 (sej/yr)	Emdollar Value (US$/yr)*
RENEWABLE RESOURCES:					
1	Sunlight	1.97E+15 J	1E+00	1.97	1,045
2	Rain, chemical	1.85E+12 J	2E+04	28.57	15,183
NONRENEWABLE RESOURCES:					
3	Soil erosion	1.90E+10 J	7.37E+04	1.40	744
INPUTS:					
4	Seeds	1.04E+09 J	3.57E+05	0.37	197
5	…				
YIELDS:					
9	Crops	1.28E+11 J	3.57E+05	45.68	24,272

Tasa eMergética para Evaluar el Uso de Recursos

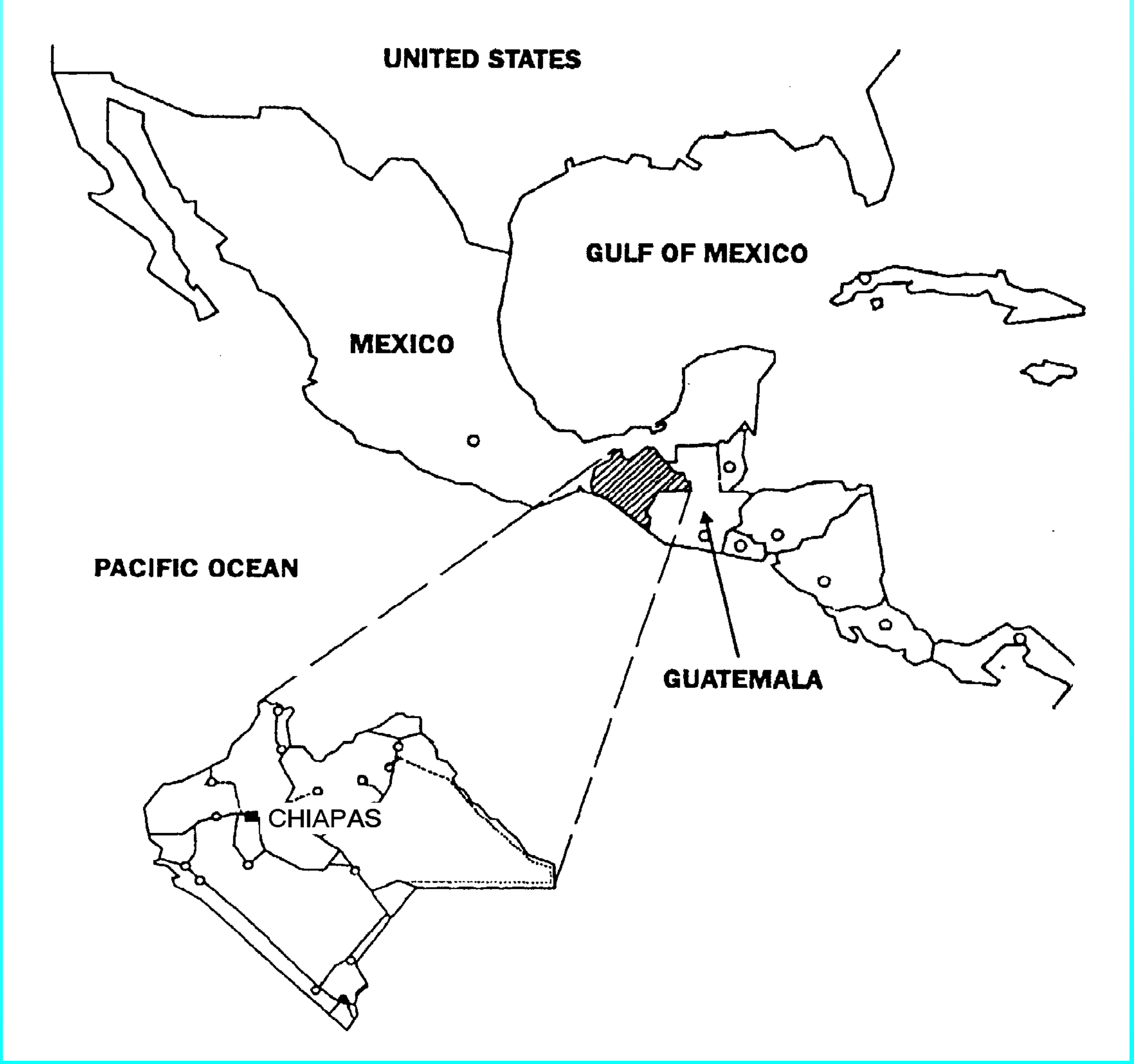


Investment Ratio
IR = (M + S) / (R + N)

Environmental Loading Ratio
ELR = (N + M + S) / R

Análisis Financieros

- B (Beneficios) = Beneficios totales financieros
- C (costos) = Costos totales financieros
- R (utilidades)= B - C
- TASA NETA UTILIDAD / COSTO
  - R/C = (utilidad) / (costo)
- Subsidios gubernamentales y préstamos


UNITED STATES
GULF OF MEXICO
MEXICO
PACIFIC OCEAN
GUATEMALA
CHIAPAS

Sistemas Analizados en este Estudio

- 400 Hectáreas Sistema Agroforestal
- Una Hectárea del Sistema de Cultivo de Café Bajo Sombra
- Una Hectárea Sistema Caña de Azúcar Industrializado

400 Hectáreas sistema Agroforestal

- Extracción de madera en Selva Tropical

- 12 lotes de 33.3 hectáreas cada uno
- 35% de árboles con dbh igual o mayor de 45 cm permitidos para cortar

400 Hectáreas de Sistema Agroforestal

400 Hectáreas de Sistema Agroforestal

Una Hectárea del Sistema de Cultivo de Café Bajo Sombra

- Monocultivo de *Coffea Arabica*
- 1,200 plantas por hectárea
- De dos a tres fertilizaciones por año
- Mano de obra intensiva (160 días/hectárea/año)

Una Hectárea del Sistema de Cultivo de Café Bajo Sombra

Una Hectárea del Sistema de Cultivo de Café Bajo Sombra

Una Hectárea Sistema Caña de Azúcar Industrializado

- Sistemas de irrigación
- Agroquímicos
- Los valores promedios obtenidos de 3,686 hectáreas
- Destrucción de ecosistemas nativos

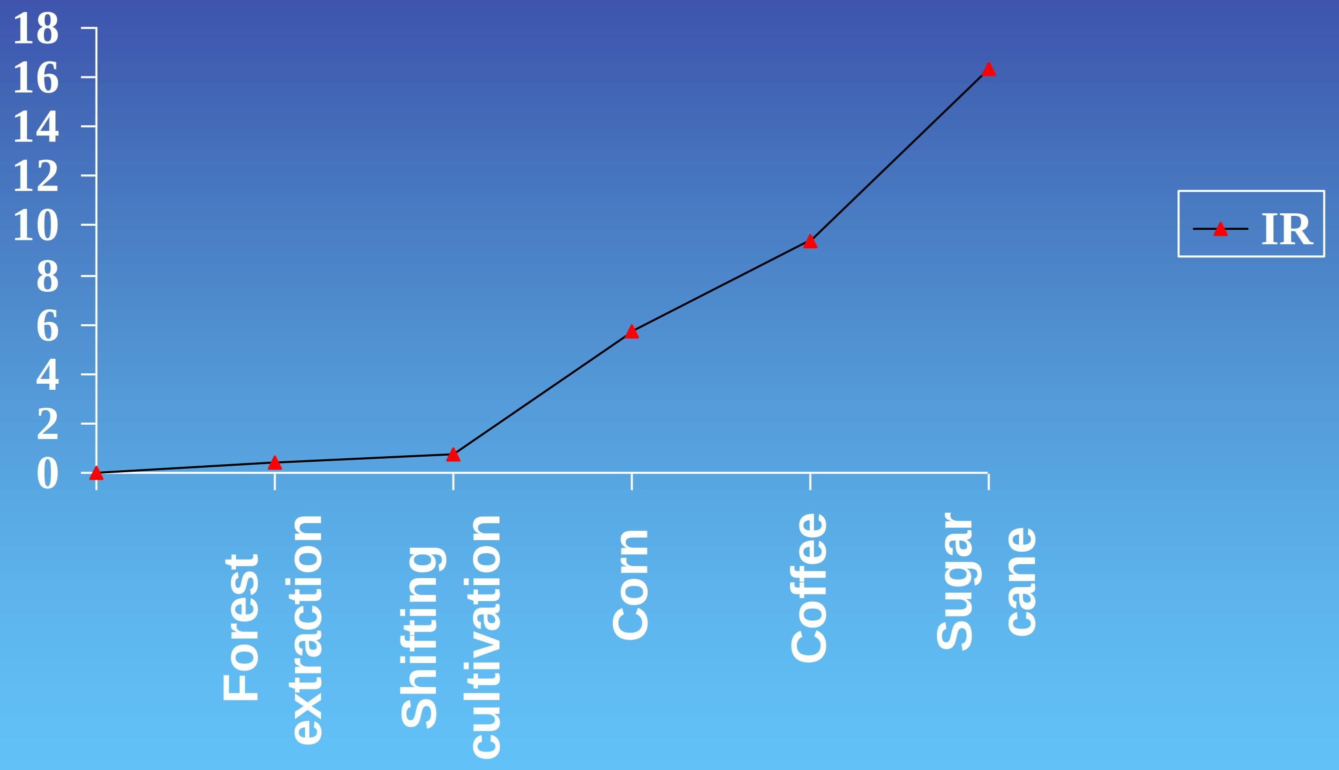
Una Hectárea Sistema Caña de Azúcar Industrializado

Otros Sistemas para Comparación

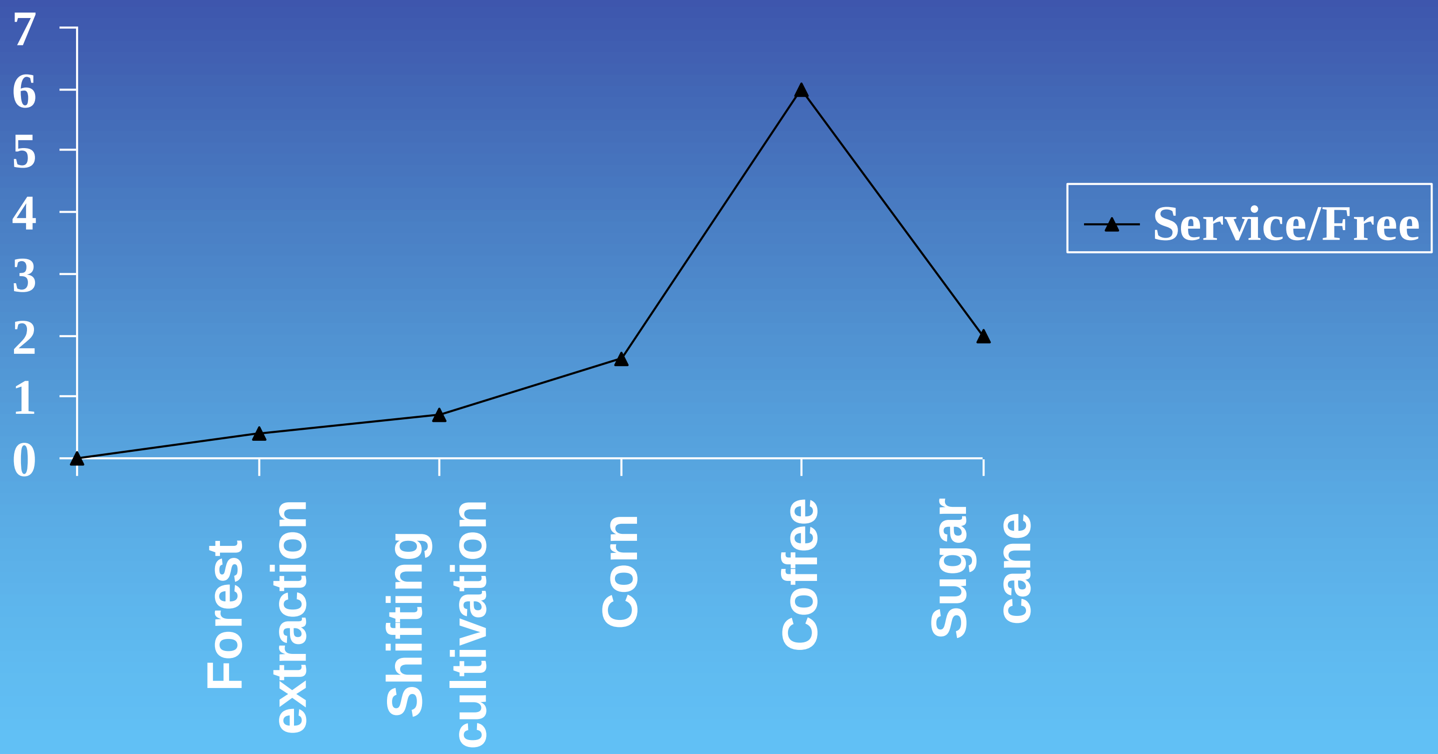
- 12.5 Hectáreas Sistema de Milpa Migratoria
  - 2.5 hectáreas cultivadas por año
  - 10.5 hectáreas en acahual
  - No agroquímicos
- Una hectárea de cultivo de maíz
  - Con agroquímicos
  - Cultivo intensivo anual

RESULTADOS Y DISCUSIÓN

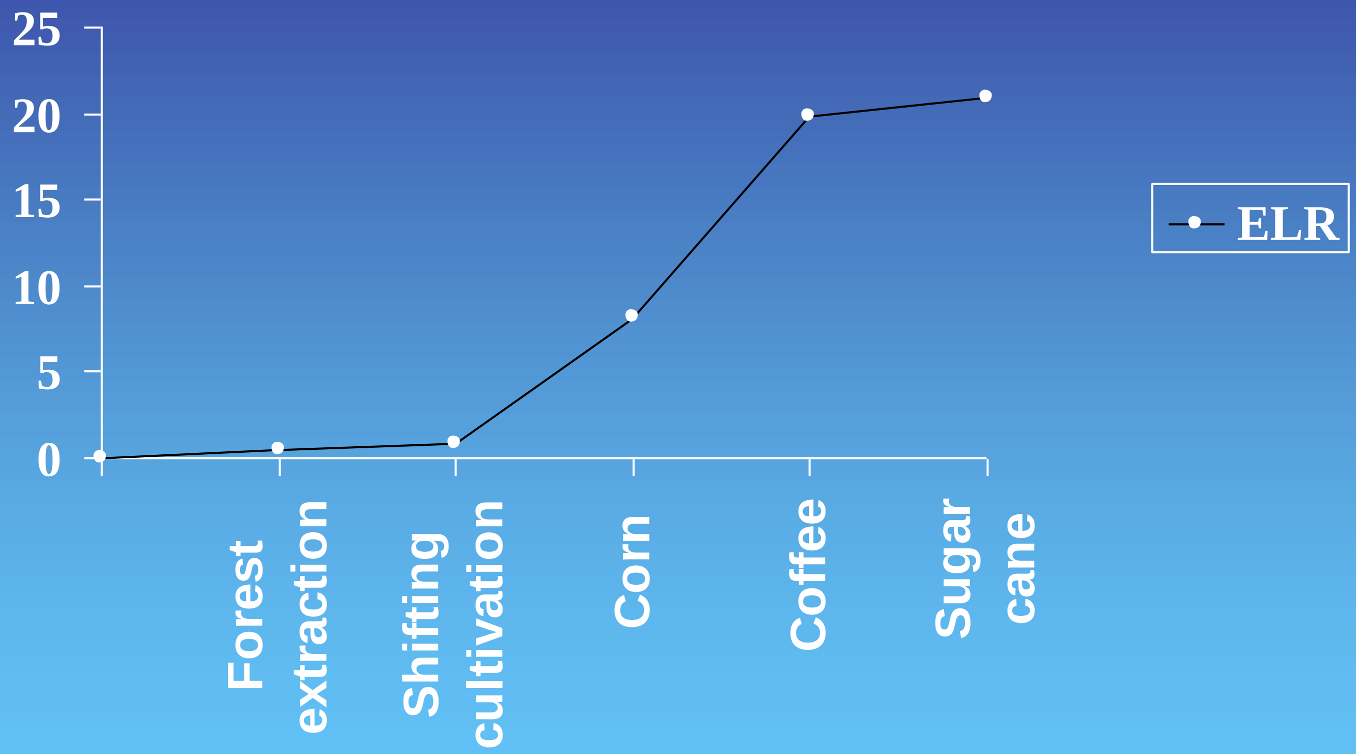
Tasas de inversión



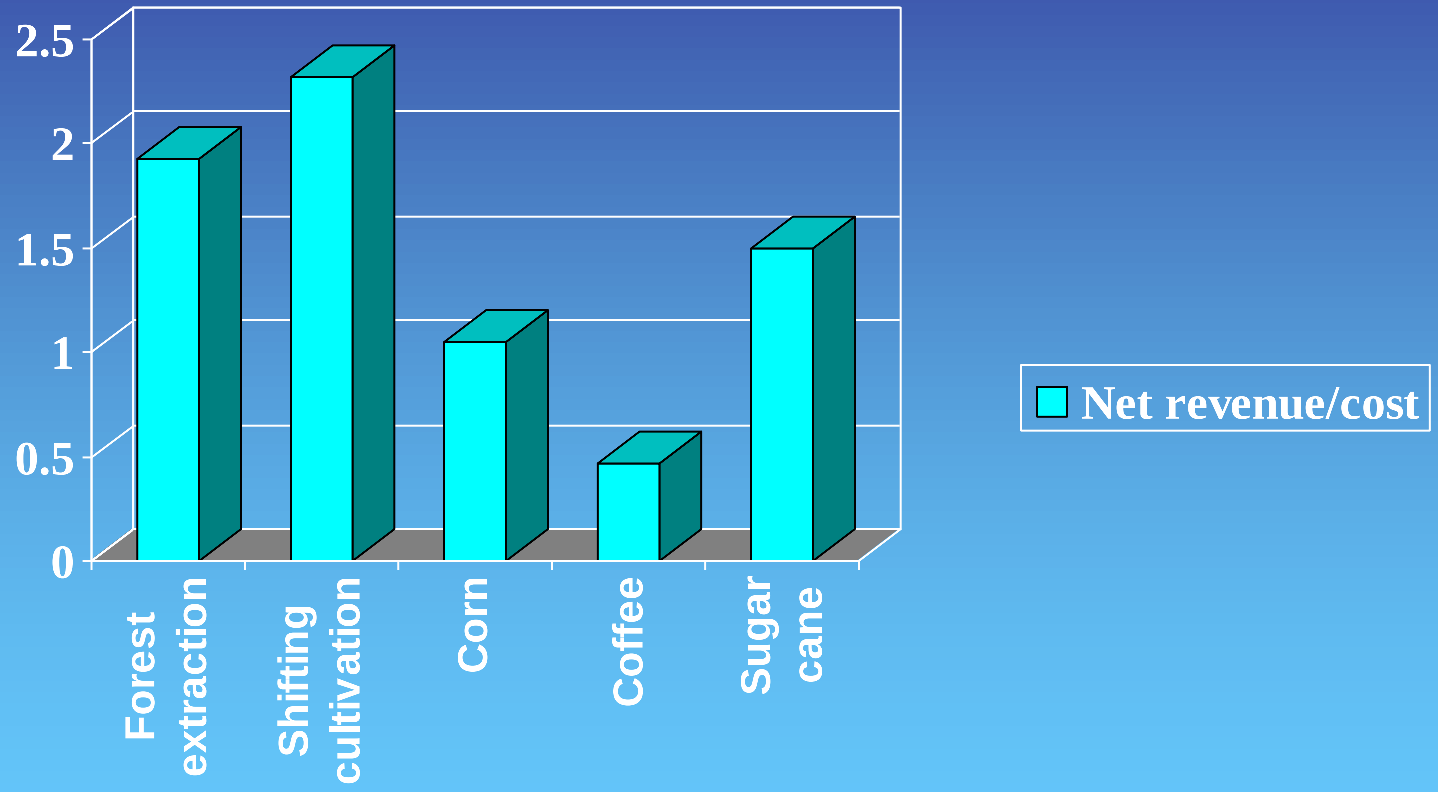
Tasas Servicio / Libre



Tasas de carga ambiental



Tasa neta utilidad / costo



400 Hectares Agro-forestry System

- ✓ Lowest investment ratio (IR=0.41)
- ✓ Highly profitable (NR/C=1.93)
- ✓ Forest conservation

- ➢ High requirement of land
- ➢ Over quota extraction (28.3 m3/ha/yr)
- ➢ Lack of law enforcement

One Hectare Shaded Coffee Cultivation System

- ✓ Maintanance of forest cover
- ✓ Adequate transition zone between protected areas and agricultural fields

- ➢ High investment ratio (IR=9.4)
- ➢ Low profitability (NR/C=0.5)
- ➢ Labor intensive (160 days/ha/yr)
- ➢ Chemical usage

One Hectare Sugar Cane Industrialized Cultivation System

- ✓ Highly profitable (NR/C=1.5)
- ✓ Not labor intensive (61 days/ha/yr)

- ➢ High external dependency (IR=16.3)
- ➢ Chemical usage (34 % of total emergy)
- ➢ 50 percent water loss
- ➢ Native ecosystems eradication

CONCLUSIONES

Sustainability of Agro-forestry and Agro-industrial Systems in Chiapas, Mexico

- Agro-forestry systems had lower investment and environmental loading ratios.
- Agro-forestry were more profitable than industrialized systems.

Sustainability of Agro-forestry and Agro-industrial Systems in Chiapas, Mexico

- Corn shifting cultivation was the most profitable (NR/C=2.3).
- Industrialized systems required less land but depended more on external resources.

Sustainability of Agro-forestry and Agro-industrial Systems in Chiapas, Mexico

- Coffee grown under shade with chemicals was labor intensive with lower profitability.

Study Limitations

- Life cycle analysis (LCA): water pollution, soil pollution, forest cut, biodiversity, etc. should be included in the analysis

Sustainability of Agro-forestry and Agro-industrial Systems in Chiapas, Mexico

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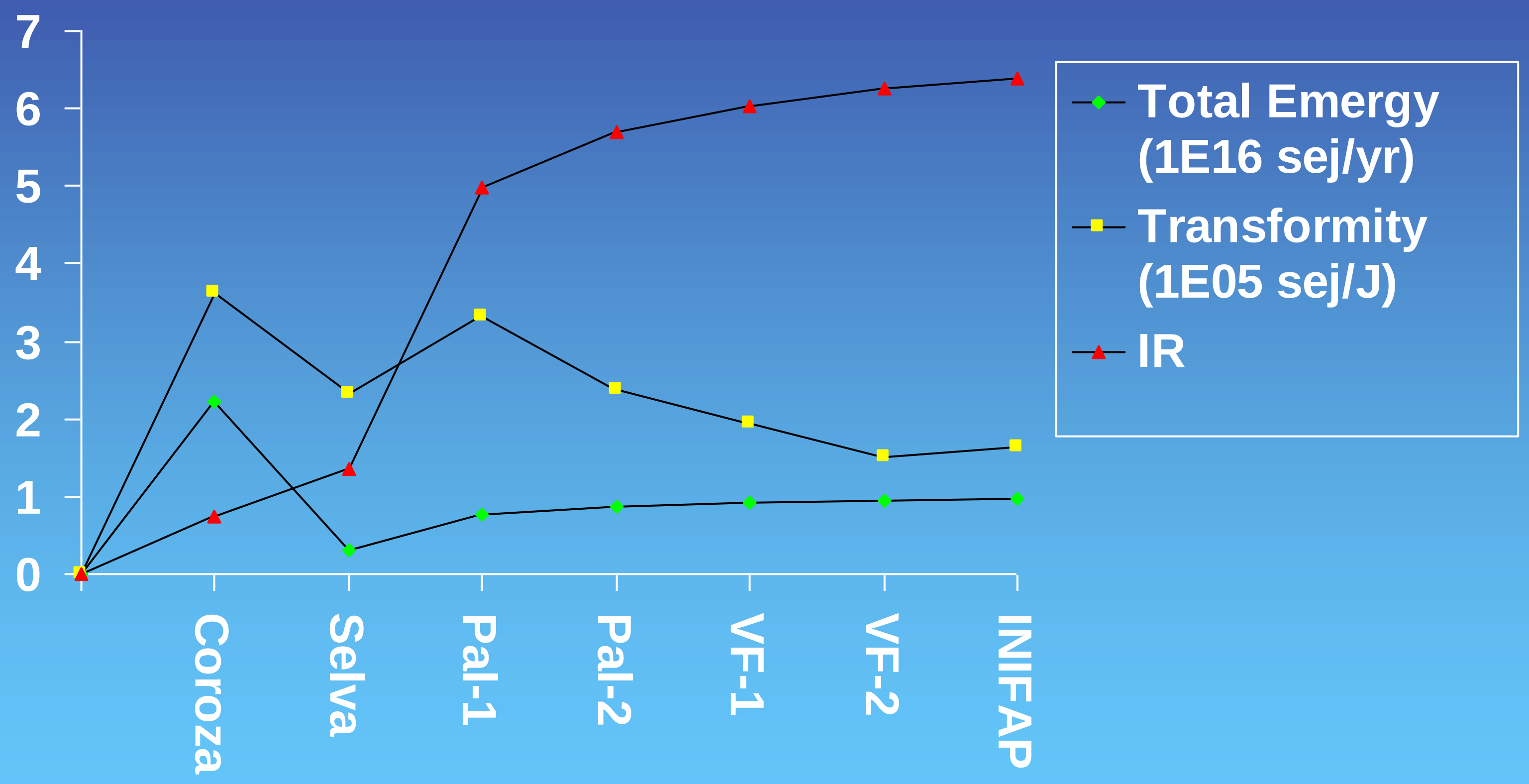
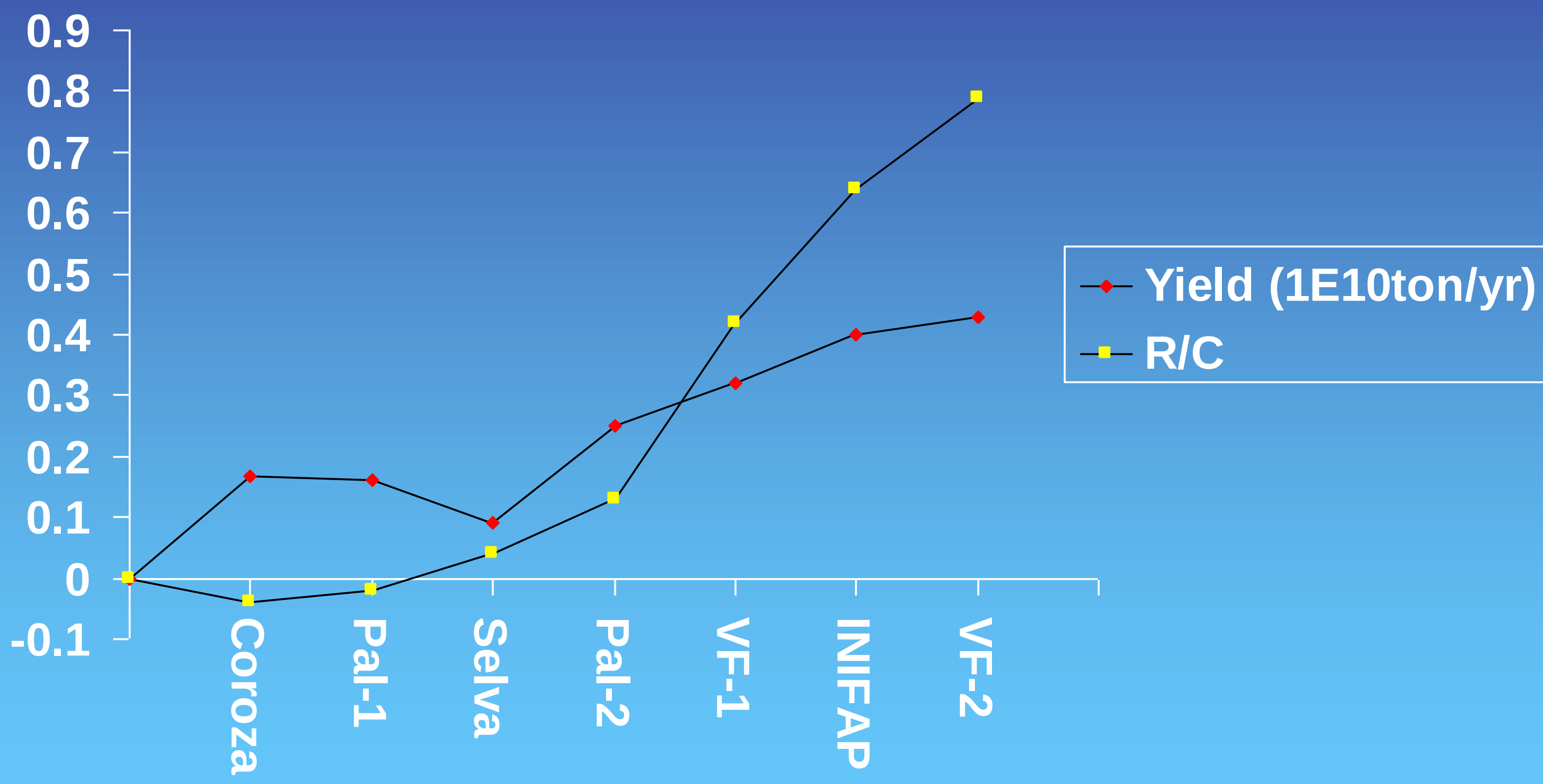
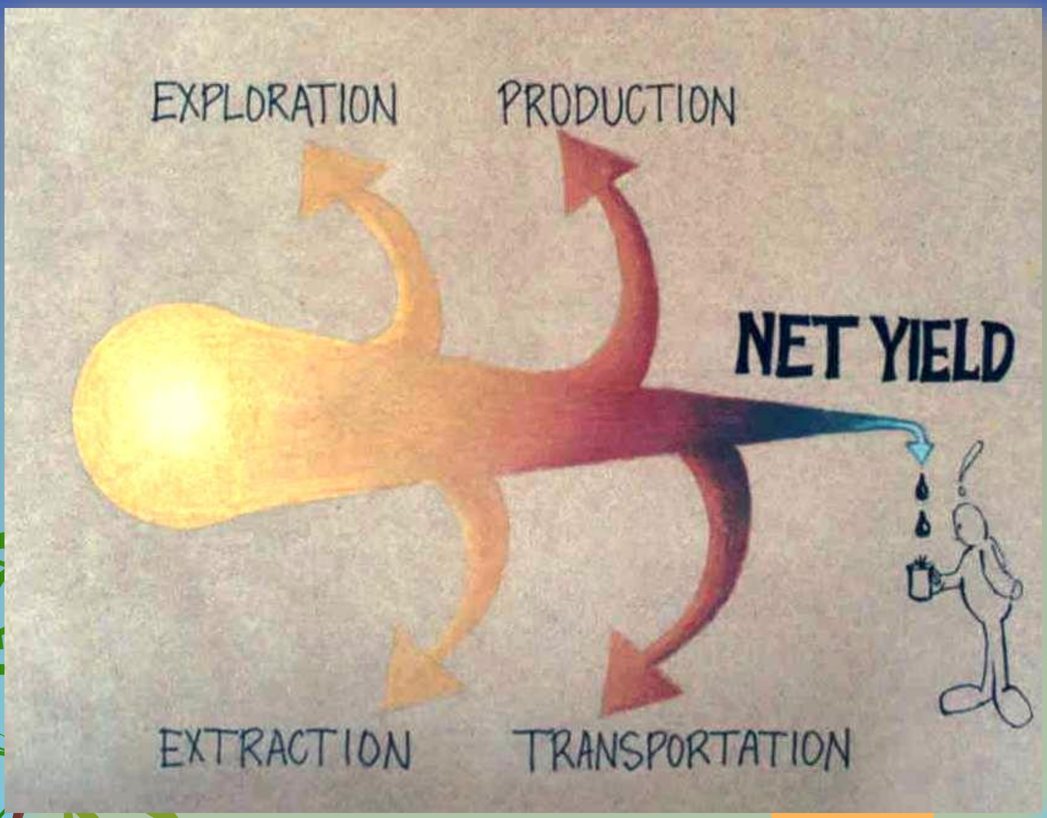
Total Emergy, Transformity and Investment Ratios for Corn Systems



Yield and Revenue Cost Ratios for Corn Systems



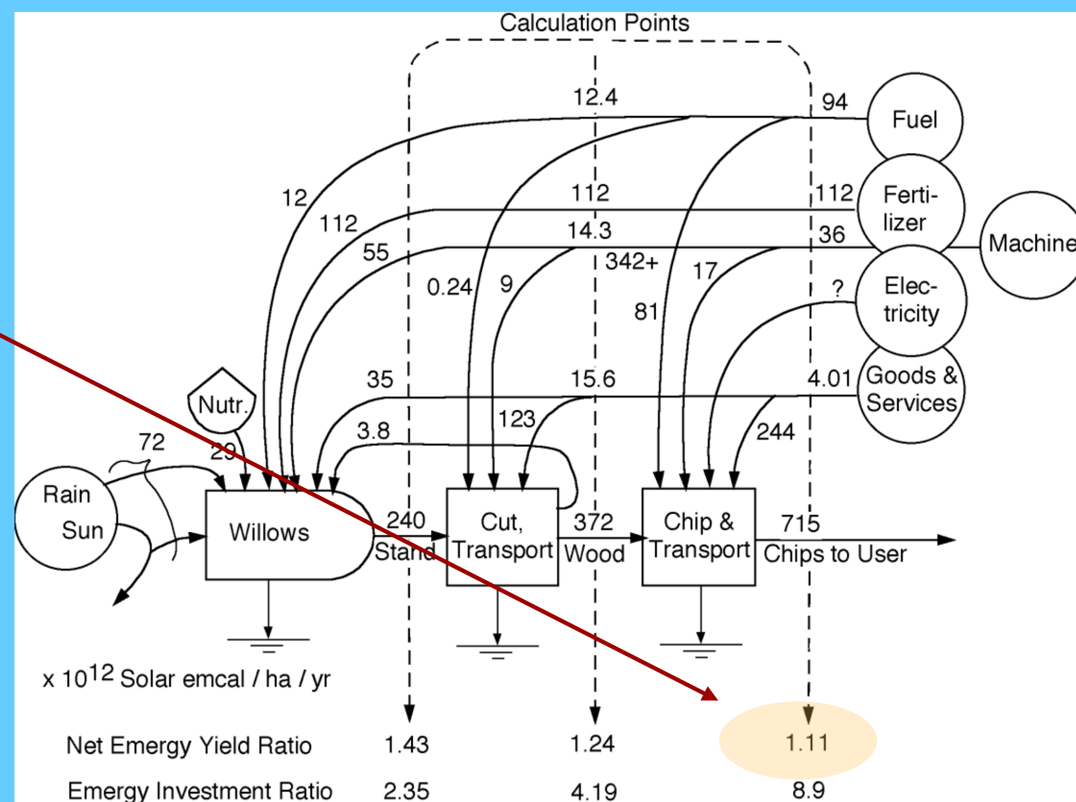
Net Energy…



We believe that to maintain society's current level of infrastructure and information processing, a net energy of about 4:1 is required.

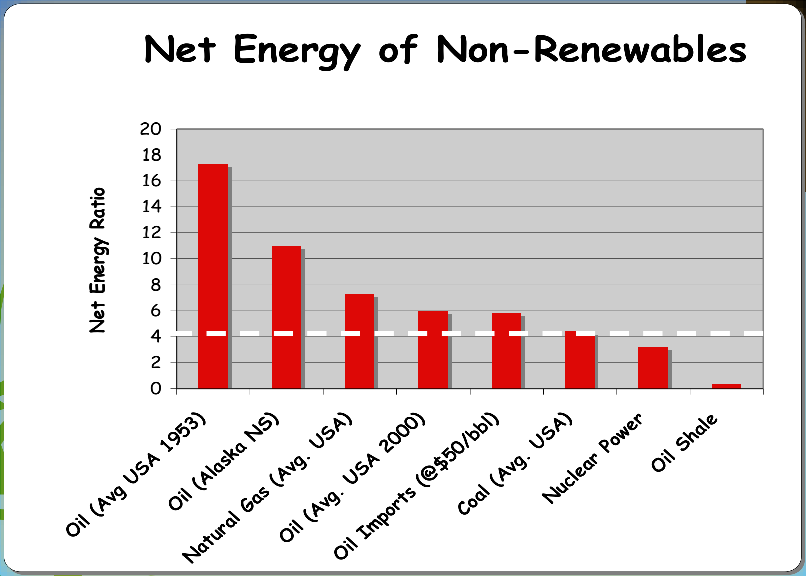
Net Energy…

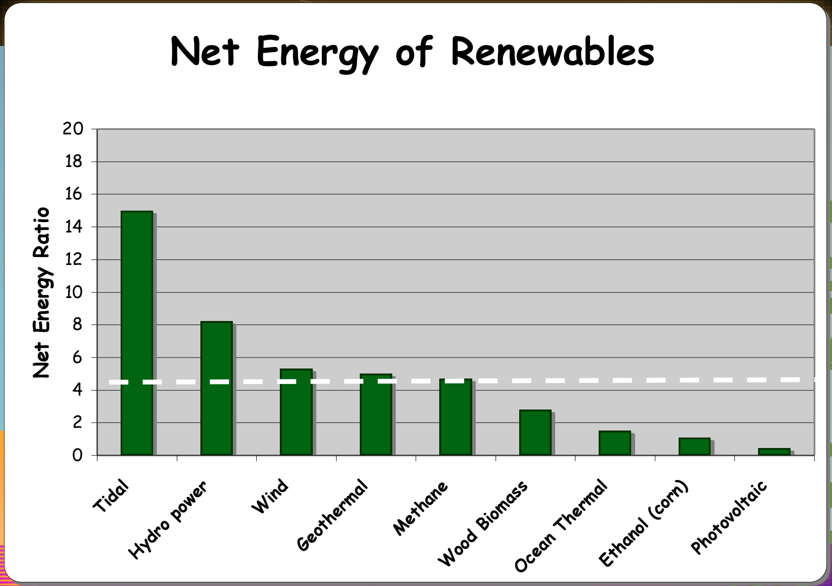
Net energy of biomass is barely 1/1



Net Energy…


Middelgrunden offshore wind farm, near Copenhagen, Denmark (55°40' N, 12°38' E).
http://www.yannarthusbertrand.org


Net Energy of Non-Renewables
Net Energy Ratio
20
18
16
14
12
10
8
6
4
2
0
Oil (Avg USA 1953)
Oil (Alaska NS)
Natural Gas (Avg. USA)
Oil (Avg. USA 2000)
Oil Imports (@$50/bbl)
Coal (Avg. USA)
Nuclear Power
Oil Shale


Net Energy of Renewables
Net Energy Ratio
20
18
16
14
12
10
8
6
4
2
0
Tidal
Hydro power
Wind
Geothermal
Methane
Wood Biomass
Ocean Thermal
Ethanol (corn)
Photovoltaic

(Pimentel & Patzek, 2005)

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Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower

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Received and accepted 30 January 2005

(Pimentel & Patzek, 2005)

Corn to Ethanol…

Table 1. Energy Inputs and Costs of Corn Production Per Hectare in the United States

Inputs	Quantity	kcal × 1000	Costs $
Labor	11.4 hrs[a]	462[b]	148.20[c]
Machinery	55 kg[d]	1,018[e]	103.21[f]
Diesel	88 L[g]	1,003[h]	34.76
Gasoline	40 L[i]	405[j]	20.80
Nitrogen	153 kg[k]	2,448[l]	94.86[m]
Phosphorus	65 kg[n]	270[o]	40.30[p]
Potassium	77 kg[q]	251[r]	23.87[s]
Lime	1,120 kg[t]	315[u]	11.00
Seeds	21 kg[v]	520[w]	74.81[x]
Irrigation	8.1 cm[y]	320[z]	123.00[aa]
Herbicides	6.2 kg[bb]	620[ee]	124.00
Insecticides	2.8 kg[cc]	280[ee]	56.00
Electricity	13.2 kWh[dd]	34[ff]	0.92
Transport	204 kg[gg]	169[hh]	61.20
Total		8,115	$916.93
Corn yield 8,655 kg/ha[ii]		31,158	kcal input: output 1:3.84

Table 2. Inputs Per 1000 l of 99.5% Ethanol Produced From Corn[a]

Inputs	Quantity	kcal × 1000	Dollars $
Corn grain	2,690 kg[b]	2,522[b]	284.25[b]
Corn transport	2,690 kg[b]	322[c]	21.40[d]
Water	40,000 L[e]	90[f]	21.16[g]
Stainless steel	3 kg[i]	12[i]	10.60[d]
Steel	4 kg[i]	12[i]	10.60[d]
Cement	8 kg[i]	8[i]	10.60[d]
Steam	2,546,000 kcal[j]	2,546[j]	21.16[k]
Electricity	392 kWh[j]	1,011[j]	27.44[l]
95% ethanol to 99.5%	9 kcal/L[m]	9[m]	40.00
Sewage effluent	20 kg BOD[n]	69[h]	6.0
Total		6,597	$453.21

5.1 E6/6.6 E6= net yield
0.77/1

(Pimentel & Patzek, 2005)

Switchgrass to Ethanol…

Table 3. Average Inputs and Energy Inputs Per Hectare Per Year for Switchgrass Production

Input	Quantity	10^3 kcal	Dollars
Labor	5 hr[a]	20[b]	$65[c]
Machinery	30 kg[d]	555	50[a]
Diesel	100 L[e]	1,000	50
Nitrogen	50 kg[e]	800	28[e]
Seeds	1.6 kg[f]	100[a]	3[f]
Herbicides	3 kg[g]	300[h]	30[a]
Total	10,000 kg yield[i] 40 million kcal yield	2,755 input/ output ratio	$230[j] 1:14.4[k]

Table 4. Inputs Per 1000 l of 99.5% Ethanol Produced From U.S. Switchgrass

Inputs	Quantities	kcal × 1000[a]	Costs
Switchgrass	2,500 kg[b]	694[c]	$250[o]
Transport, switchgrass	2,500 kg[d]	300	15
Water	125,000 kg[e]	70[f]	20[m]
Stainless steel	3 kg[g]	45[g]	11[g]
Steel	4 kg[g]	46[g]	11[g]
Cement	8 kg[g]	15[g]	11[g]
Grind switchgrass	2,500 kg	100[h]	8[h]
Sulfuric acid	118 kg[i]	0	83[n]
Steam production	8.1 tons[i]	4,404	36
Electricity	660 kWh[i]	1,703	46
Ethanol conversion to 99.5%	9 kcal/L[j]	9	40
Sewage effluent	20 kg (BOD)[k]	69[l]	6
Total		7,455	$537

5.1 E6/7.5 E6= net yield 0.68/1

(Pimentel & Patzek, 2005)

Wood Cellulose to Ethanol…

Table 5. Inputs Per 1000 l of 99.5% Ethanol Produced From U.S. wood cellulose

Inputs	Quantities	kcal × 1000[a]	Costs
Wood, harvest (fuel)	2,500 kg[b]	400[c]	$ 250[n]
Machinery	5 kg[m]	100[m]	10[o]
Replace nitrogen	50 kg[c]	800	28[o]
Transport, wood	2,500 kg[d]	300	15
Water	125,000 kg[e]	70[f]	20[o]
Stainless steel	3 kg[g]	45[g]	11[g]
Steel	4 kg[g]	46[g]	11[g]
Cement	8 kg[g]	15[g]	11[g]
Grind wood	2,500 kg	100[h]	8[h]
Sulfuric acid	118 kg[b]	0	83[p]
Steam production	8.1 tons[b]	4,404	36
Electricity	666 kWh[bl]	1,703	46
Ethanol conversion to 99.5%	9 kcal/L[i]	9	40
Sewage effluent	20 kg (BOD)[j]	69[k]	6
Total		8,061	$575

5.1 E6/8.1E6= net yield 0.63/1

(Pimentel & Patzek, 2005)

Soybean to Biodiesel…

Table 6. Energy Inputs and Costs in Soybean Production Per Hectare in the U.S.

Inputs	Quantity	kcal × 1000	Costs $
Labor	7.1 h[a]	284[b]	92.30c
Machinery	20 kg[d]	360[e]	148.00[f]
Diesel	38.8 L[a]	442[g]	20.18
Gasoline	35.7 L[a]	270[h]	13.36
LP gas	3.3 L[a]	25[i]	1.20
Nitrogen	3.7 kg[j]	59[k]	2.29[l]
Phosphorus	37.8 kg[j]	156[m]	23.44[n]
Potassium	14.8 kg[j]	48[o]	4.59[p]
Lime	4800 kg[v]	1,349[d]	110.38[v]
Seeds	69.3 kg[a]	554[q]	48.58[r]
Herbicides	1.3 kg[j]	130[e]	26.00
Electricity	10 kWh[d]	29[s]	0.70
Transport	154 kg[t]	40[u]	46.20
Total		3,746	$537.22
Soybean yield 2,668 kg/ha[w]		9,605	kcal input: output 1:2.56

Table 7. Inputs Per 1,000 kg of Biodiesel Oil From Soybeans

Inputs	Quantity	kcal × 1000	Costs $
Soybeans	5,556 kg[a]	7,800[a]	$1,117.42[a]
Electricity	270 kWh[b]	697[c]	18.90[d]
Steam	1,350,000 kcal[b]	1,350[b]	11.06[e]
Cleanup water	160,000 kcal[b]	160[b]	1.31[e]
Space heat	152,000 kcal[b]	152[b]	1.24[e]
Direct heat	440,000 kcal[b]	440[b]	3.61[e]
Losses	300,000 kcal[b]	300[b]	2.46[e]
Stainless steel	11 kg[f]	158[f]	18.72[g]
Steel	21 kg[f]	246[f]	18.72[g]
Cement	56 kg[f]	106[f]	18.72[g]
Total		11,878	$1,212.16

9.0 E6/11.9E6= net yield
0.75/1

(Pimentel & Patzek, 2005)

Sunflower to Biodiesel…

Table 8. Energy Inputs and Costs in Sunflower Production Per Ha in the U.S.

Inputs	Quantity	kcal × 1000	Costs $
Labor	8.6 h[a]	344[b]	111.80[c]
Machinery	20 kg[d]	360[e]	148.00[f]
Diesel	180 L[a]	1,800[g]	93.62[h]
Nitrogen	110 kg[j]	1,760[k]	68.08[l]
Phosphorus	71 kg[j]	293[m]	44.03[n]
Potassium	100 kg[j]	324[o]	34.11[p]
Lime	1000 kg[j]	281[d]	23.00[v]
Seeds	70 kg[a]	560[q]	49.07[r]
Herbicides	3 kg[j]	300[v]	60.00[i]
Electricity	10 kWh[d]	29[s]	0.70
Transport	270 kg[t]	68[u]	81.00
Total		6,119	$601.61
Sunflower yield 1,500 kg/ha[w]		4,650	kcal input: output 1:0.76

Table 9. Inputs Per 1,000 kg of Biodiesel Oil From Sunflower

Inputs	Quantity	kcal × 1000	Costs $
Sunflower	3,920 kg[a]	15,990[a]	$1.570.20[a]
Electricity	270 kWh[b]	697[c]	18.90[d]
Steam	1,350,000 kcal[b]	1,350[b]	11.06[e]
Cleanup water	160,000 kcal[b]	160[b]	1.31[e]
Space heat	152,000 kcal[b]	152[b]	1.24[e]
Direct heat	440,000 kcal[b]	440[b]	3.61[e]
Losses	300,000 kcal[b]	300[b]	2.46[e]
Stainless steel	11 kg[f]	158[f]	18.72[g]
Steel	21 kg[f]	246[f]	18.72[g]
Cement	56 kg[f]	106[f]	18.72[g]
Total		19,599	$1,662.48

9.0 E6/19.6E6= net yield 0.46/1

Pimentel & Patzek, 2005 …

Energy outputs from ethanol produced using corn, switchgrass, and wood biomass were each less than the respective fossil energy inputs. The same was true for producing biodiesel using soybeans and sunflower, however, the energy cost for producing soybean biodiesel was only slightly negative compared with ethanol production. Findings in terms of energy outputs compared with the energy inputs were: • Ethanol production using corn grain required 29% more fossil energy than the ethanol fuel produced. • Ethanol production using switchgrass required 50% more fossil energy than the ethanol fuel produced. • Ethanol production using wood biomass required 57% more fossil energy than the ethanol fuel produced. • Biodiesel production using soybean required 27% more fossil energy than the biodiesel fuel produced (Note, the energy yield from soy oil per hectare is far lower than the ethanol yield from corn). • Biodiesel production using sunflower required 118% more fossil energy than the biodiesel fuel produced.

Table 1. Typical biofuel production systems from agricultural crops.

Indicators of performance	Biodiesel[a]	Ethanol in temperate areas	Ethanol in (sub)tropical areas
Gross energy yield (GJ · ha^{-1} · yr^{-1})	20–40	40–80	80[b]–130[c]
Net energy yield (GJ · ha^{-1} · yr^{-1})	<0–10	<0–30	50[b]–70[c]
Output–input energy ratio	0.6–1.3	0.5–1.7	3.0[b]–2.5[c]
Net to gross ratio (F*/F1)	<0–0.2	<0–0.4	0.66[b]–0.60[c]
Water requirement (t · ha^{-1} · yr^{-1})	4000–7000	4000–8000	10,000[b]–15,000[c]
Energy throughput (net MJ/h)	<0–250	<0–1000	250[b]–1600[c]
Best-performing system	oilseed rape	corn–sorghum	sugarcane
Land requirement (ha/net GJ)	0.100	0.033	0.020[b]–0.014[c]
Water requirement (t/net GJ)	500	170	200[b]–200[c]
Labor requirement (h/net GJ)	4	1	4[b]–0.6[c]

[a]Trans-methylester from oil seeds (sunflower, rapeseed, or soybeans). Sunflower and soybean systems have net energies close to or less than zero.
[b]Low-input production, as in the Brazilian ProAlcohol Project (Giampietro et al. 1997a).
[c]High-input production, as reported in Pimentel et al. (1988).

INDICE DE PRODUCCIÓN NETA DE EMERGÍA

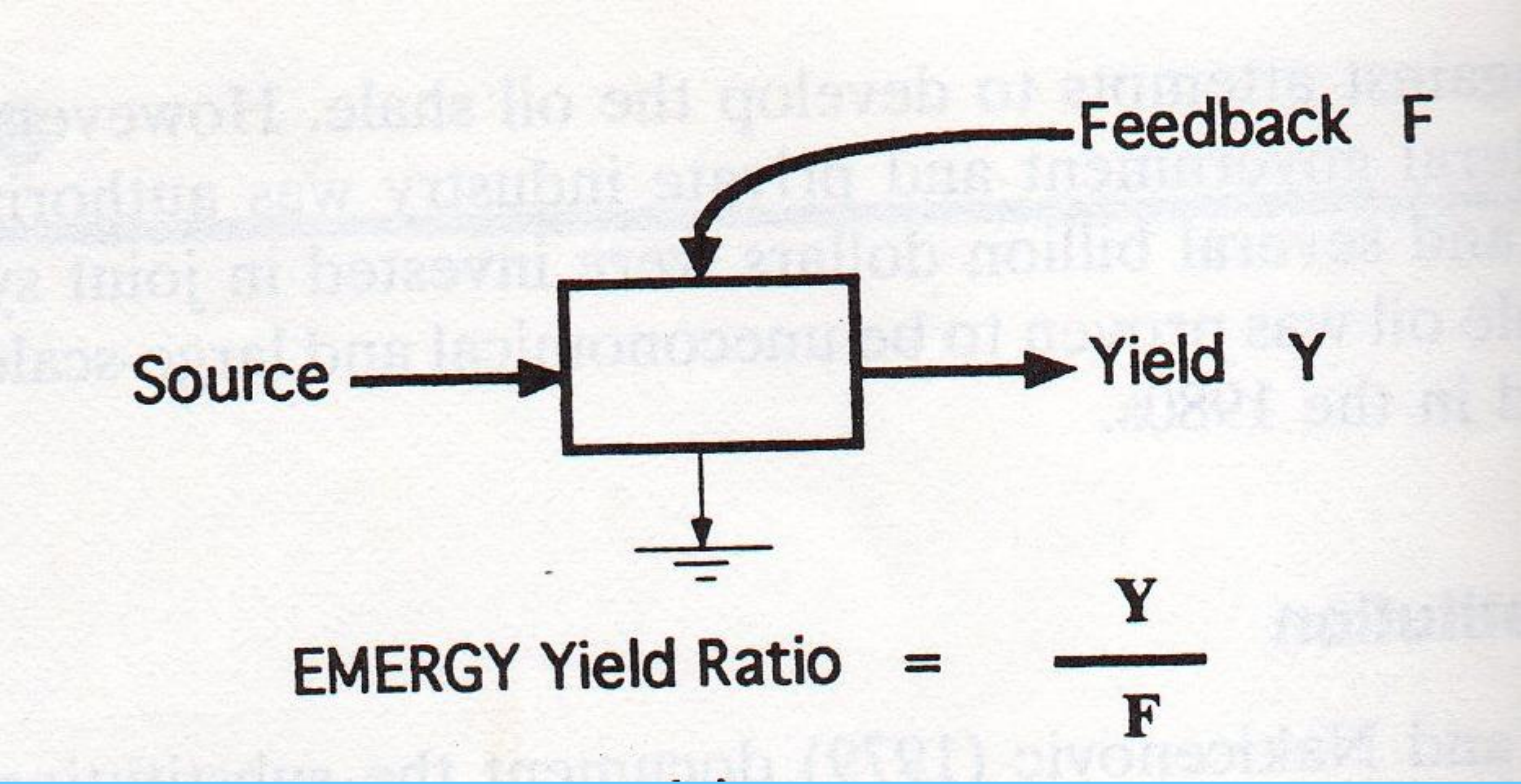

DIAGRAMA EMERGÉTICO DE PRODUCCIÓN DE ETHANOL DE CAÑA DE AZÚCAR

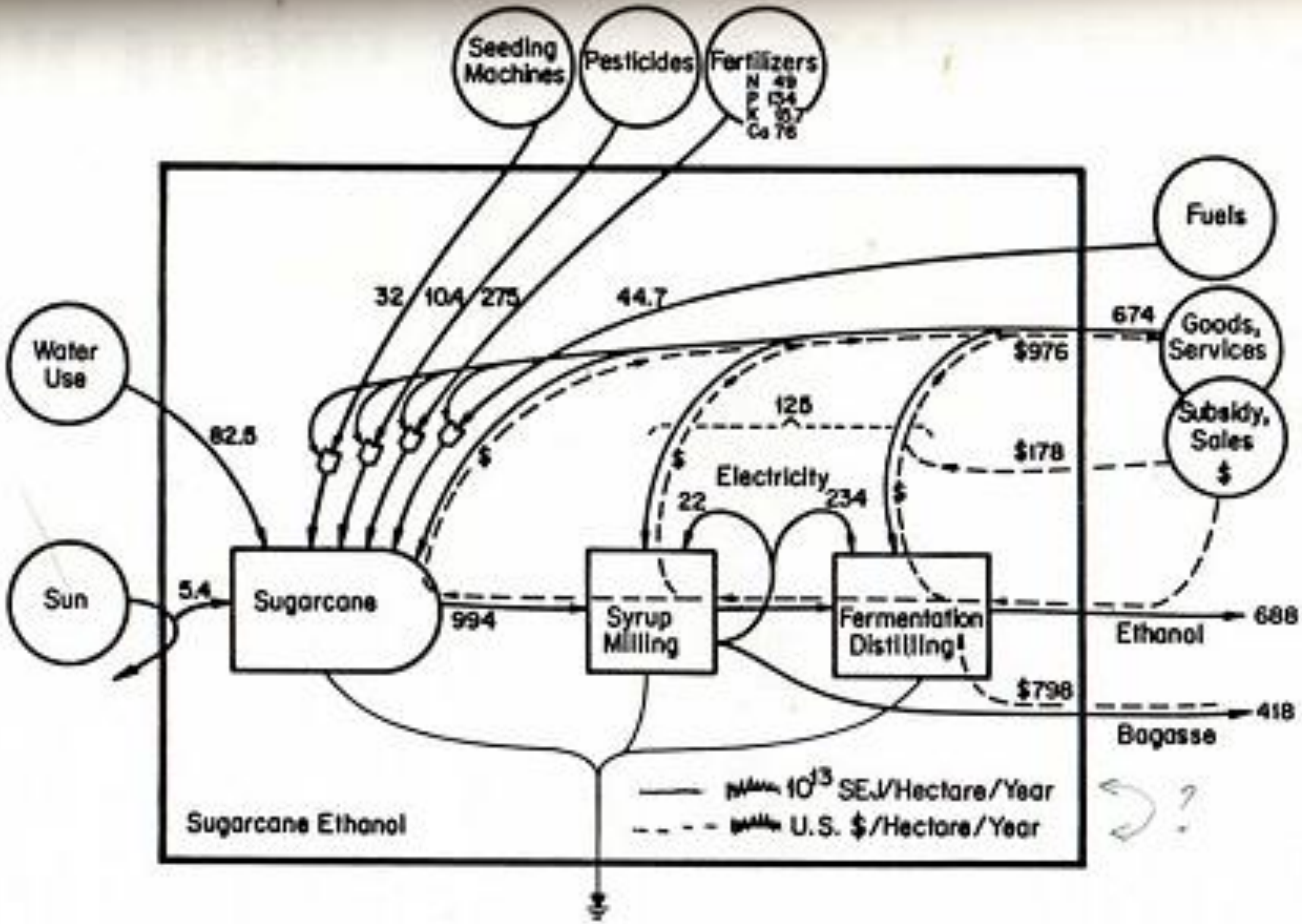

Figure 8.5. Energy systems diagram of sugarcane-ethanol system in Bahia Brazil, with solar EMERGY and dollar costs per hectare pe marked on the pathways (E. C. Odum and H. T. Odum, 1984; Odum, Brown, and Christianson, 1986).

EMERGÍA NETA DE FUENTES DE CALOR

NET EMERGY OF HEAT SOURCES

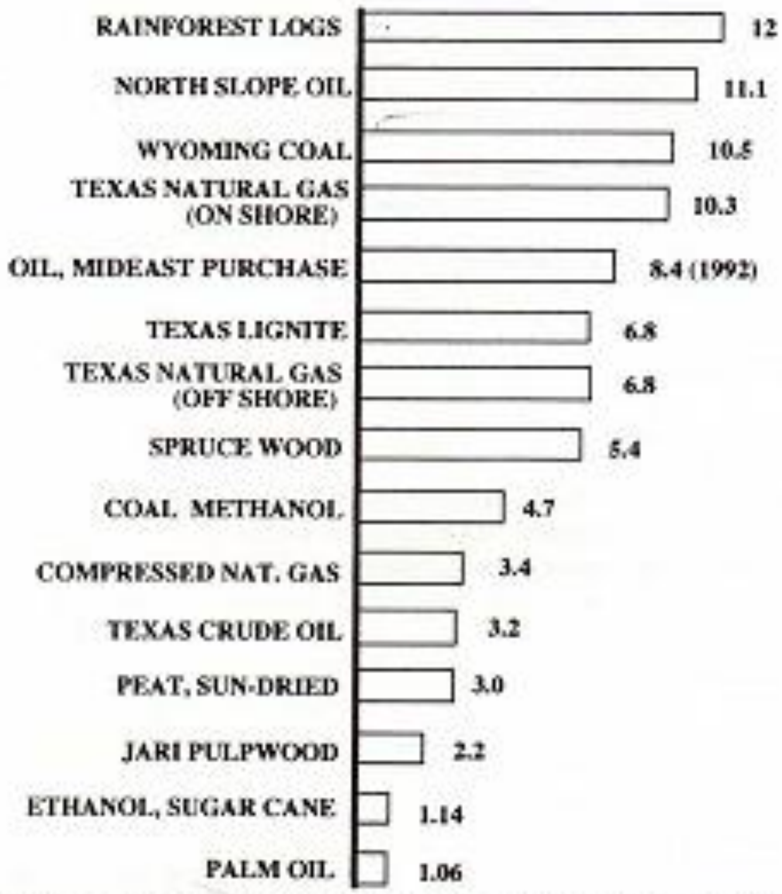

Figure 8.3. EMERGY yield ratio of fuels: Examples of rainforest logs from Odum and Odum (1983); North Slope oil from Brown et al., (1993); Wyoming coal from Ballentine (1976); Texas natural gas—shore and offshore—coal methanol, compressed natural gas, and Texas crude oil from King and Schmandt, (1991); Mideast oil purchase and Texas lignite from Odum et al. (1987a); Jari pulpwood and palm oil from Odum et al. (1986); spruce wood from Doherty et al. (1995); sugarcane, Figure 8.5; Peat, Table 5.2.