



**Universidade de São Paulo
Escola Superior de Agricultura “Luiz de Queiroz”
Departamento de Engenharia de Biosistemas**



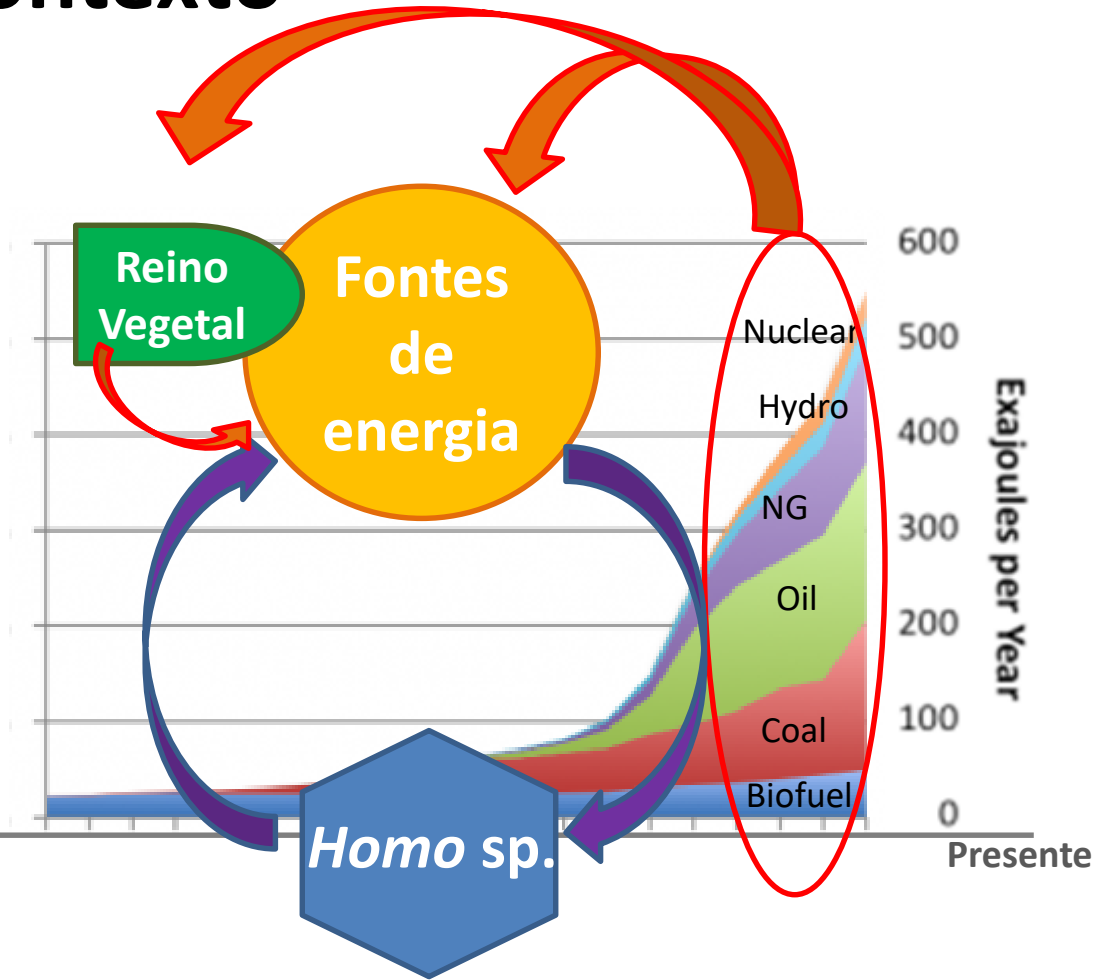
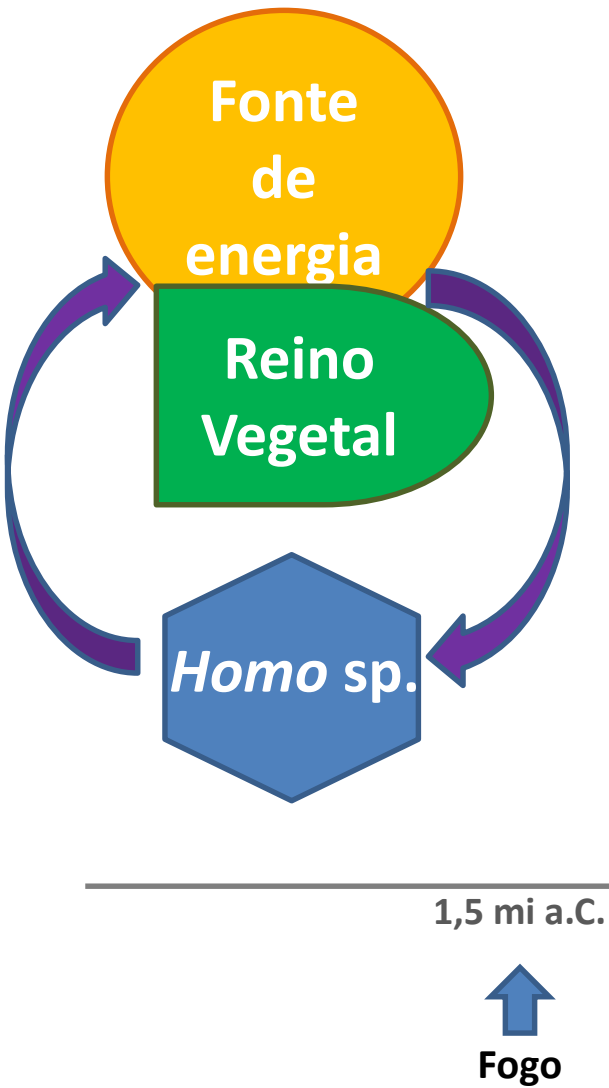
LEB 410 - Mudanças Climáticas e Agricultura

Aula 8 - Intensificação agrícola sustentável

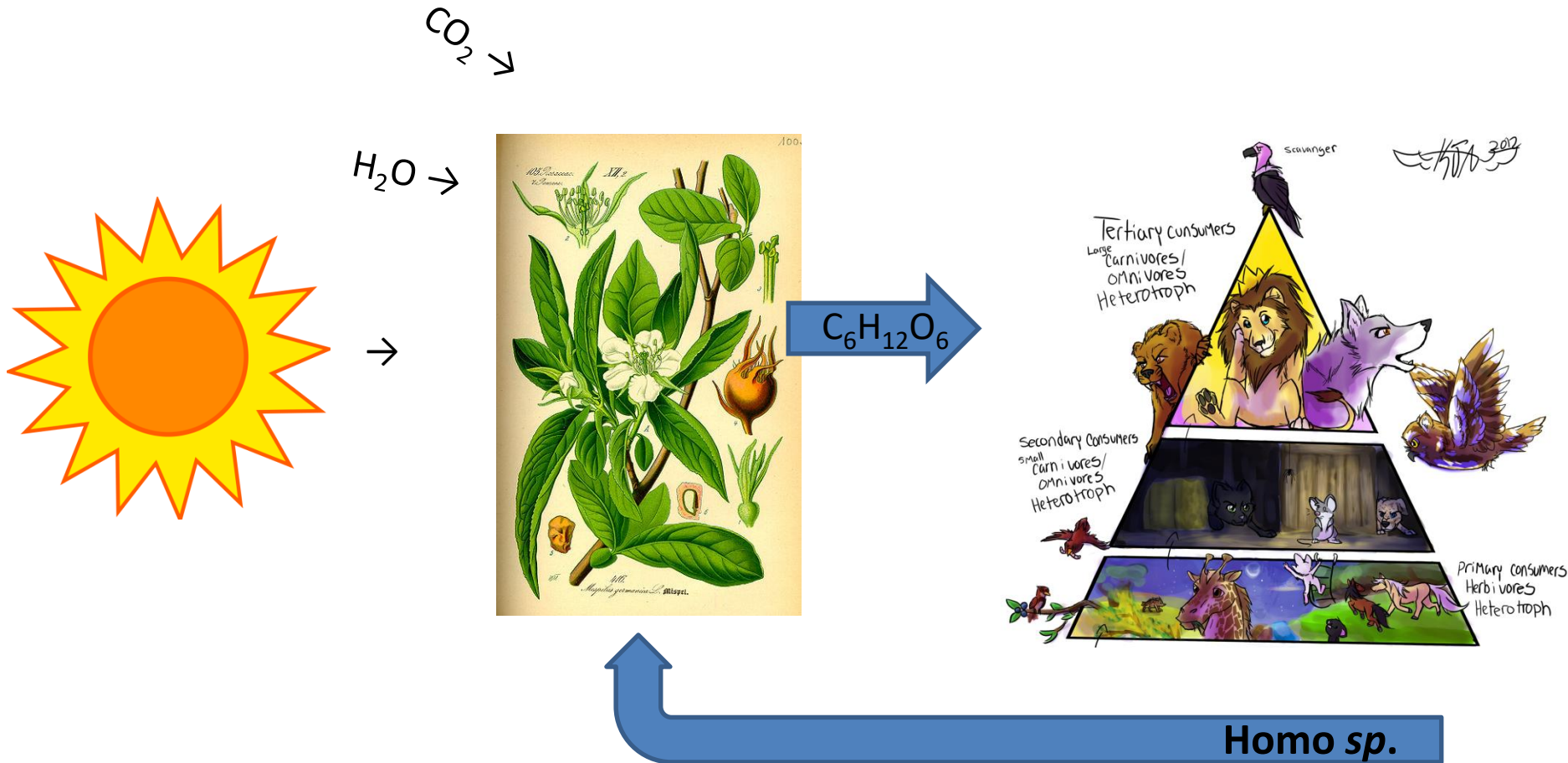
Prof. Thiago L. Romanelli
romanelli@usp.br

14 de outubro de 2019

Contexto



Energia e a vida



“No esforço em existir, a vantagem deve estar nos organismos cuja estratégia de captura de energia são mais eficientes em usá-la na preservação da espécie.”

Lotka (1910)

O início da humanidade



Australopithecus

Homo habilis

H. erectus

H. neanderthalensis

H. sapiens
Cro-Magnon

5 milhões

2,3 milhões

1,8 mi

1,5 mi

100 mil

80 mil

40 mil anos

↑
Migração
da África

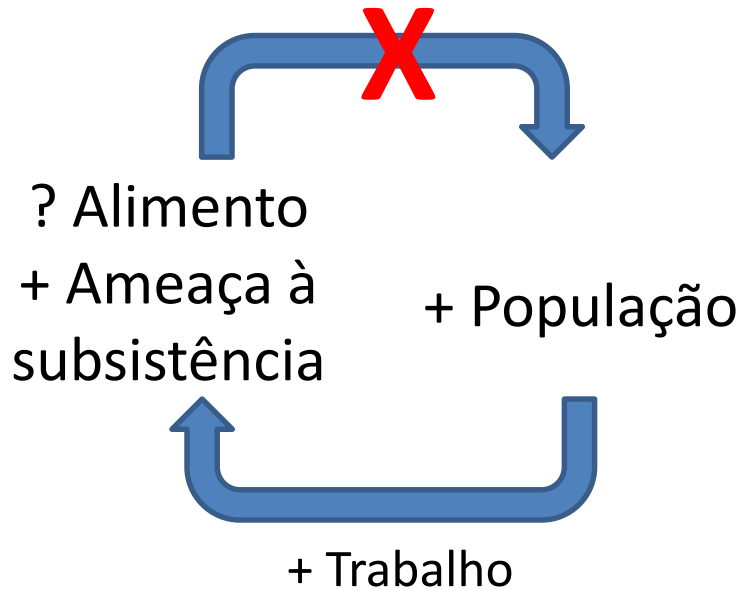
↑
Fogo

↑
Troca ferramentas
e **informação**,
técnicas de caça.
Agricultores.

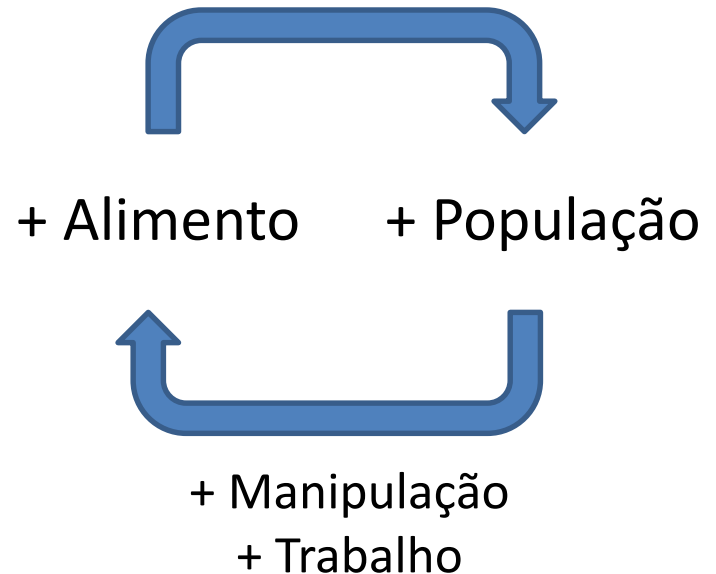
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Pinturas

Transição da caça-coleta à agricultura

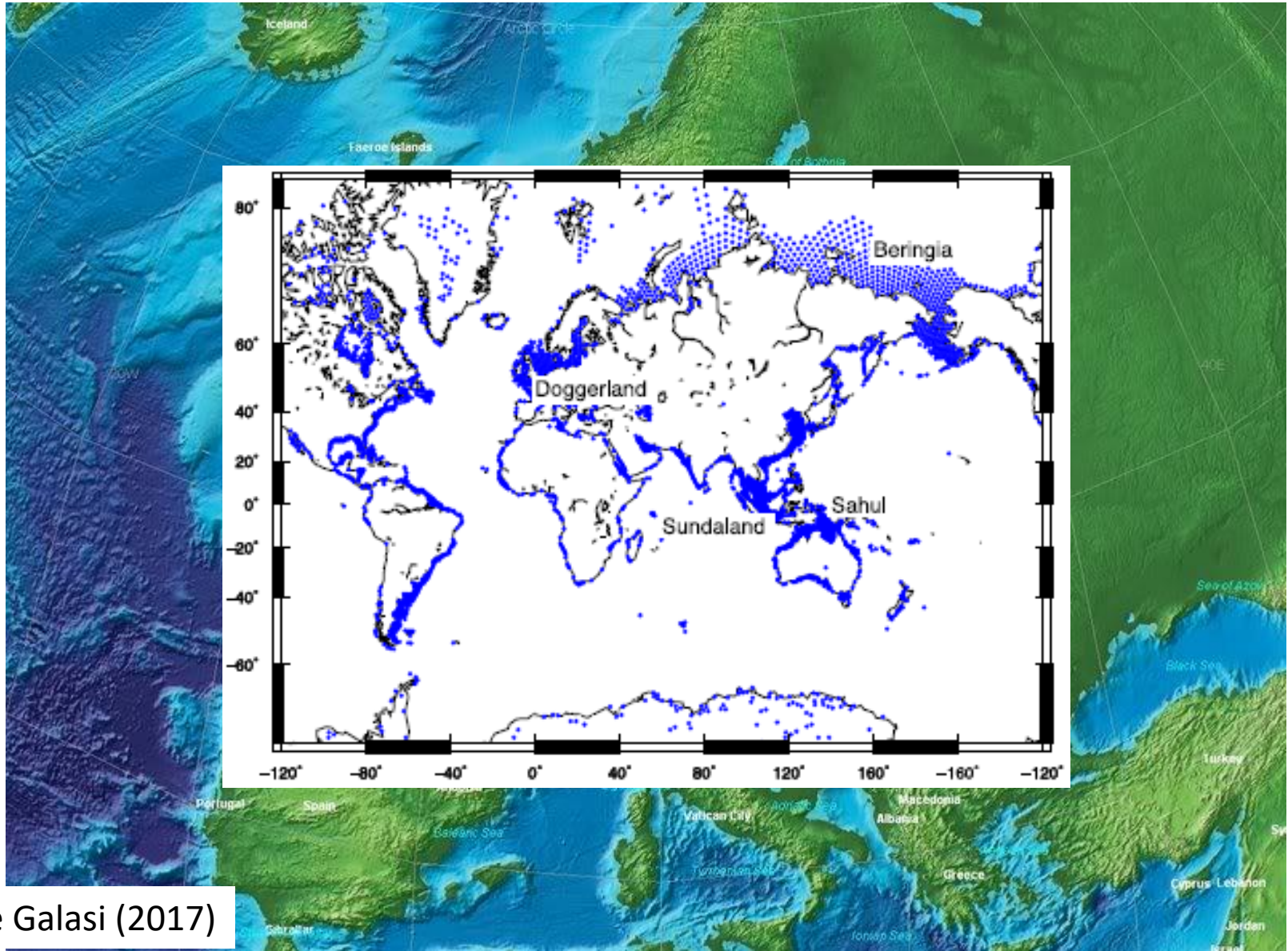
Caça



Agricultura



Transição da caça-coleta à agricultura



Transição da caça-coleta à agricultura



The Fall of Man (Michelangelo Buonarroti, 1512)

“E do suor do teu rosto comerás, ...” (Genesis 3:19).

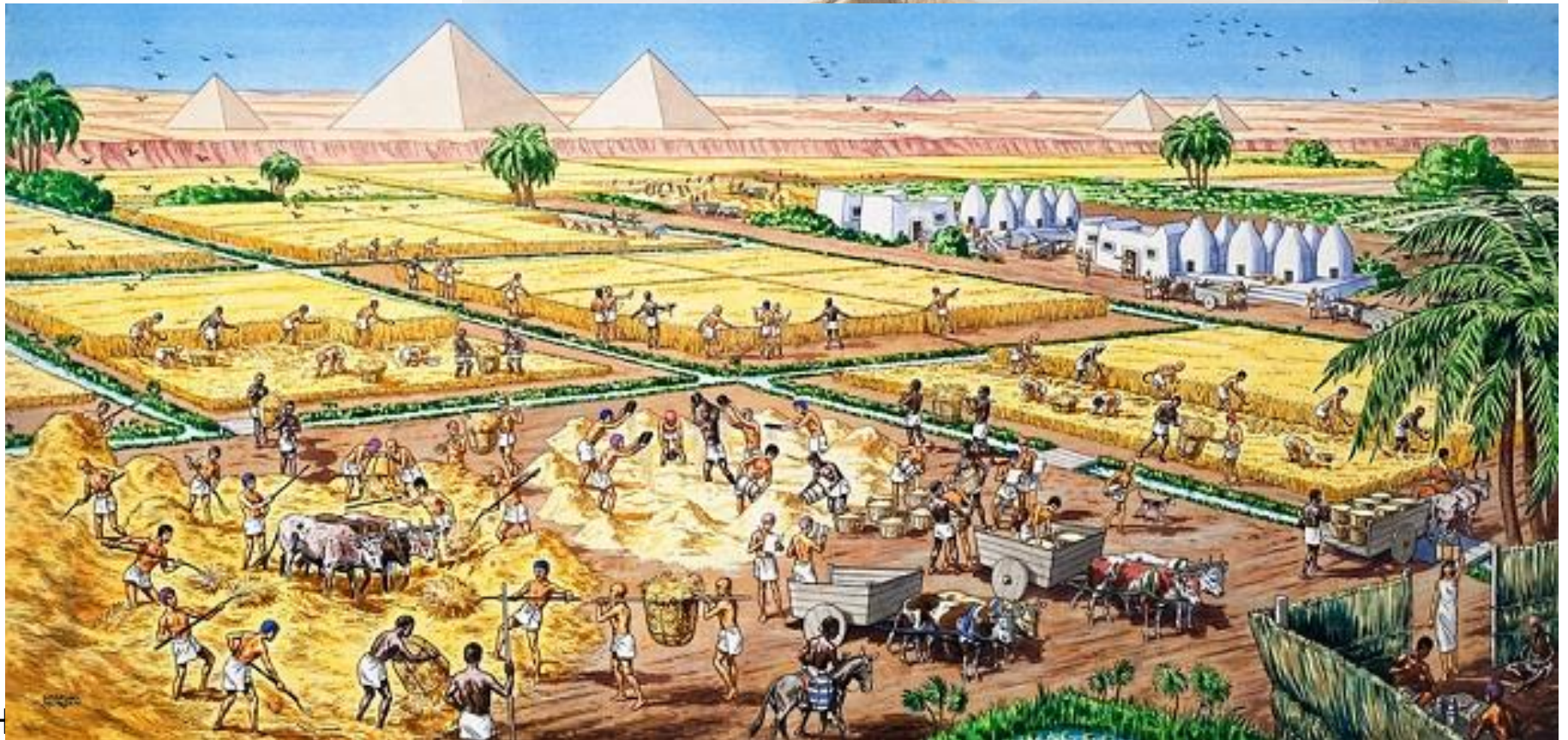
Revolução Neolítica

- 10 mil anos atrás
- Agricultura em larga escala
- Manipulação da cadeia alimentar como base do sistema energético



Museu Nacional da Dinamarca

Agricultura promotora da civilização



Agricultura promotora da civilização



Roma Antiga

3 milhões de escravos para 4
milhões de homens livres (28 DC)

Agricultura promotora da civilização



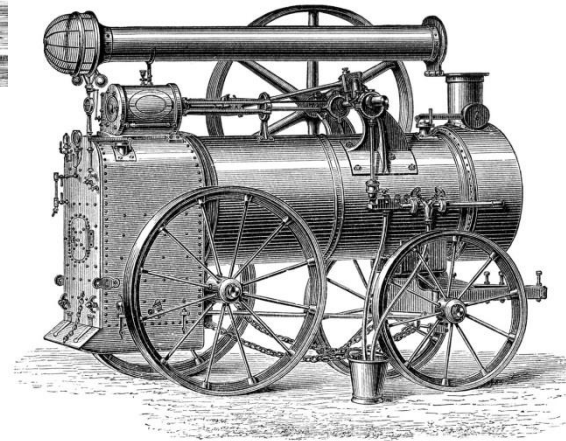
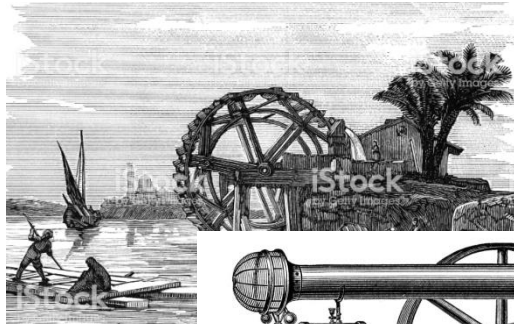
Agricultura promotora da civilização

- Estratégias para alta densidade populacional:
 1. Intensificação;



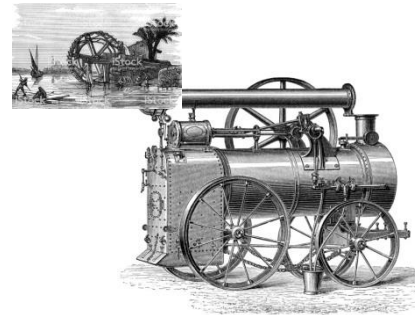
Agricultura promotora da civilização

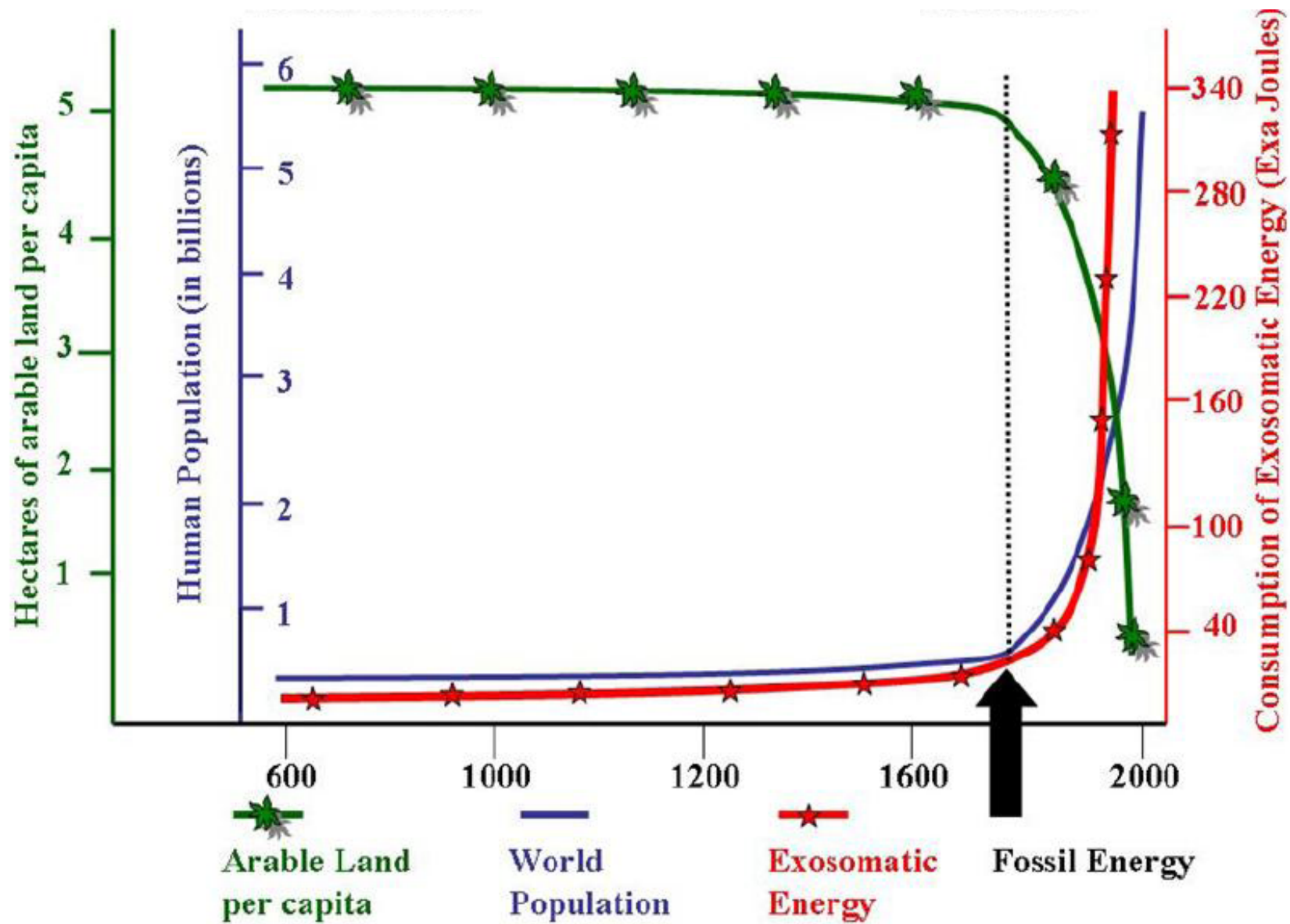
- Estratégias para alta densidade populacional:
 1. Intensificação;
 2. Novos meios;



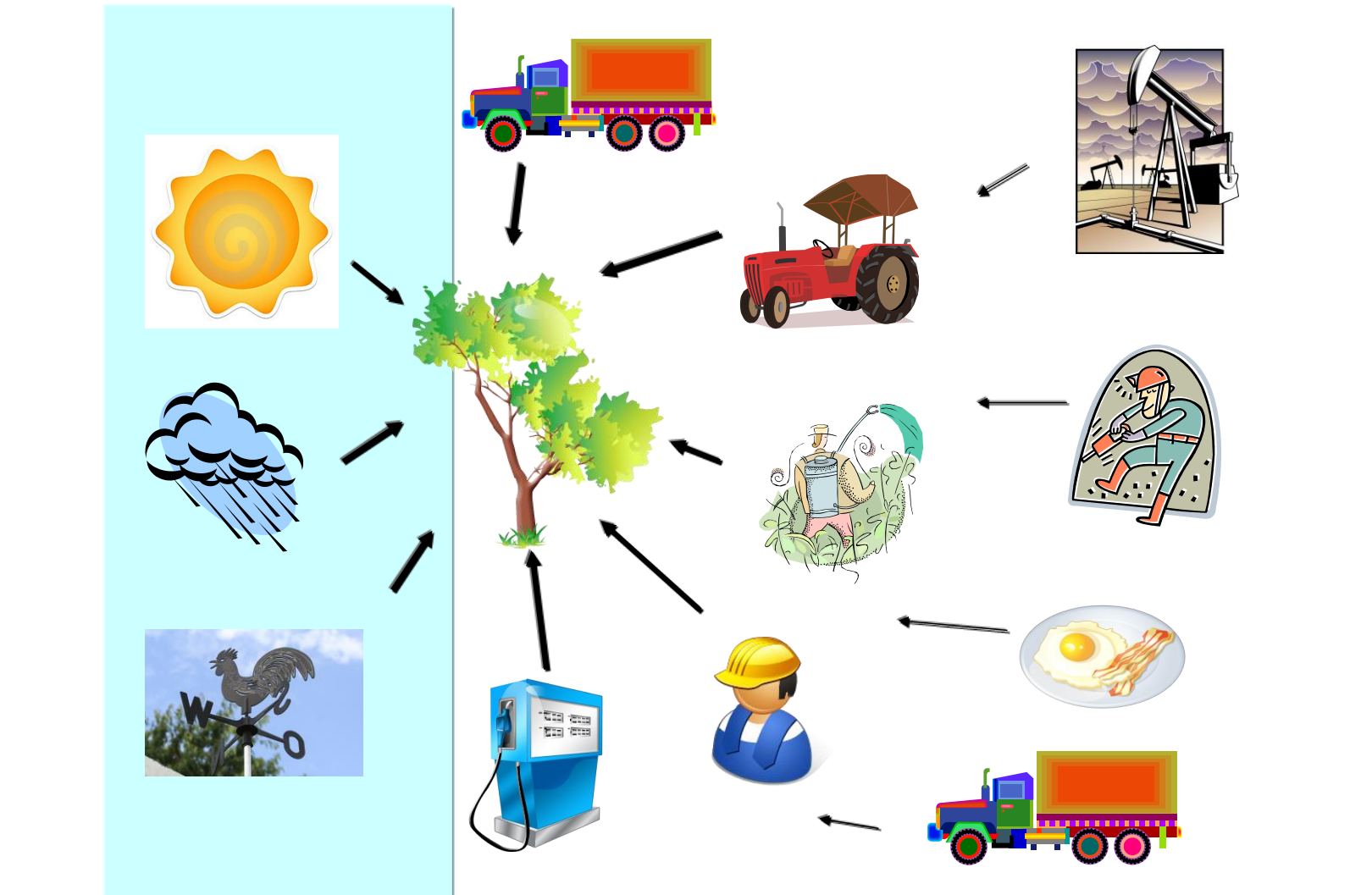
Agricultura promotora da civilização

- Estratégias para alta densidade populacional:
 1. Intensificação;
 2. Novos meios;
 3. Exploração.



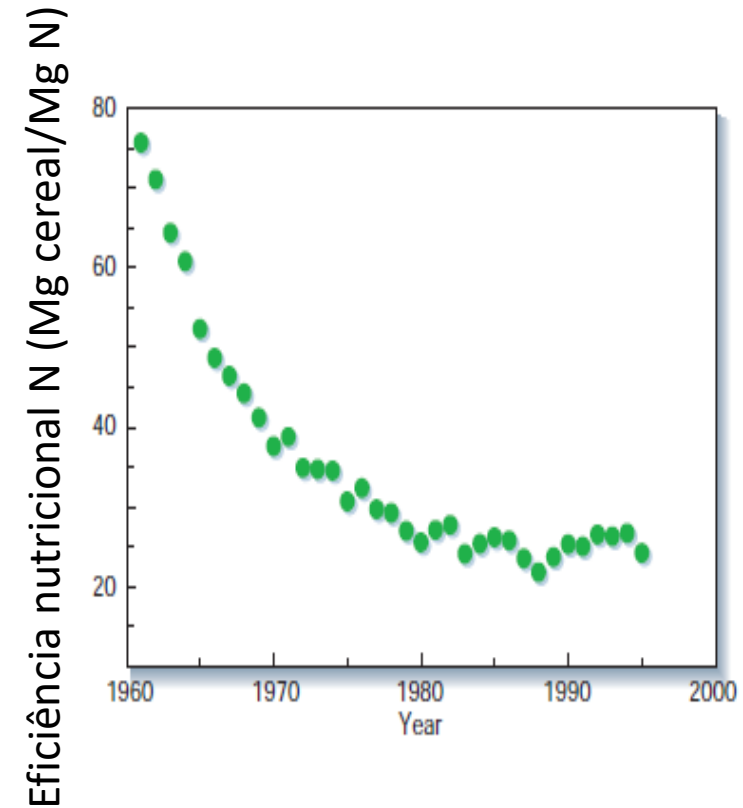


Convergência de Recursos Naturais



Intensificação

	Ag. Neolítica	Ag. Moderna
Tempo (h)	1150	17
	MJ/ha	MJ/ha
Mão-de-obra	27	0
Máquinas	4	358
Sementes	9	33
Diesel	0	502
NPK + defensivos	0	717
Irrigação	0	186
Secagem	0	167
Transporte e outros	0	91
Total	40	2054
Produtividade	1603 (2 t/ha)	4437 (5,4 t/ha)
Saída/Entrada	40	2,16



Revolução Verde

Tabela 1 – Consumo de insumos e aumento de produtividade desde a Revolução Verde no Brasil. FAO (2018).

Insumo	Aumento no consumo (%)	Período
N	7830	1961-2016
P ₂ O ₅	3349	1961-2016
K ₂ O	7999	1961-2016
Inseticida	290	1990-2015
Herbicida	861	1990-2015
Fungicida	686	1990-2015
Tratores	994	1961-2006
Área agricultável	88	1961-2015
Cultura	Aumento na Produtividade (%)	Período
Milho	227	1961-2016
Arroz	222	1961-2016
Soja	158	1961-2016
Cana-de-açúcar	73	1961-2016

ENERGIA E ECONOMIA

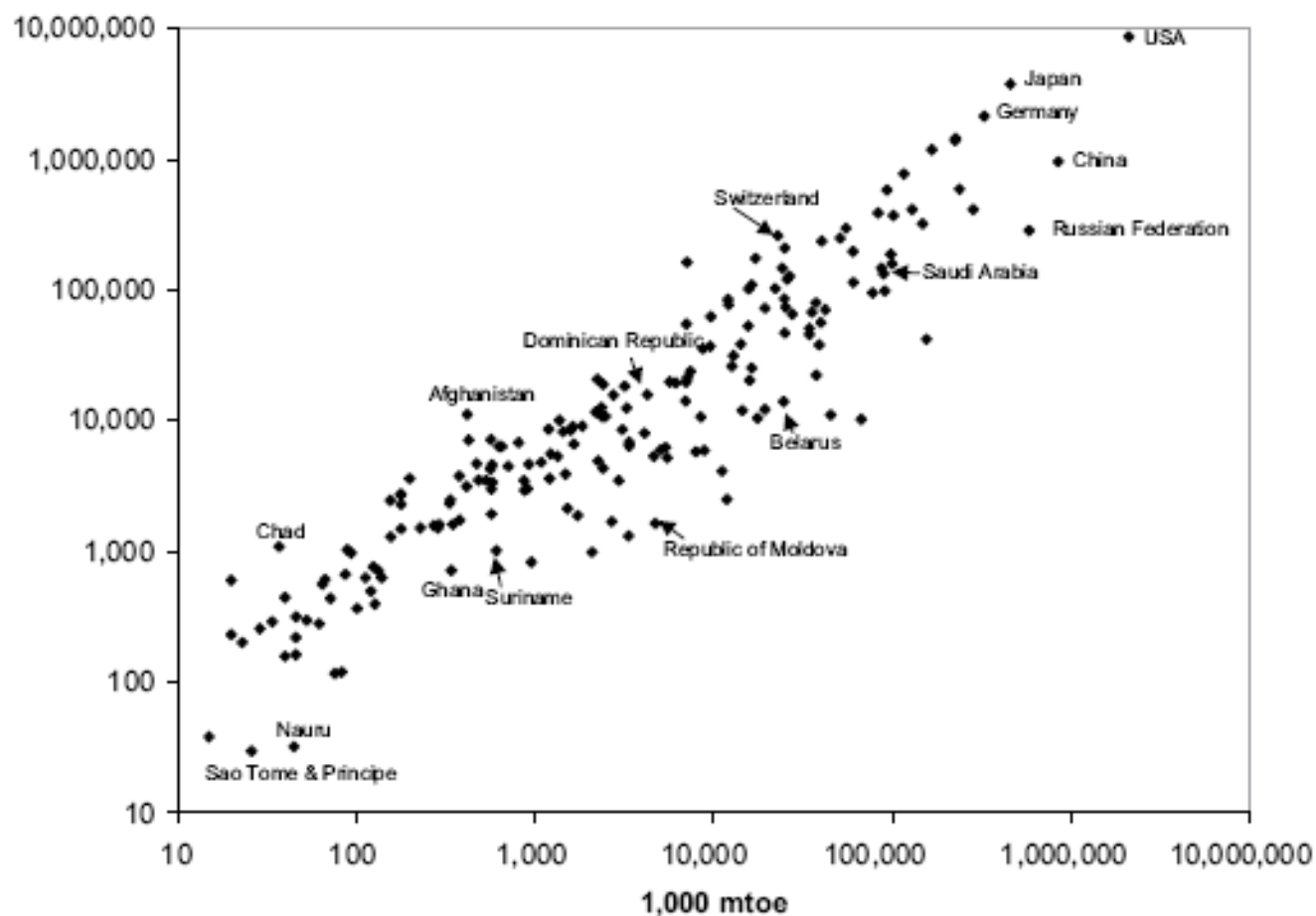
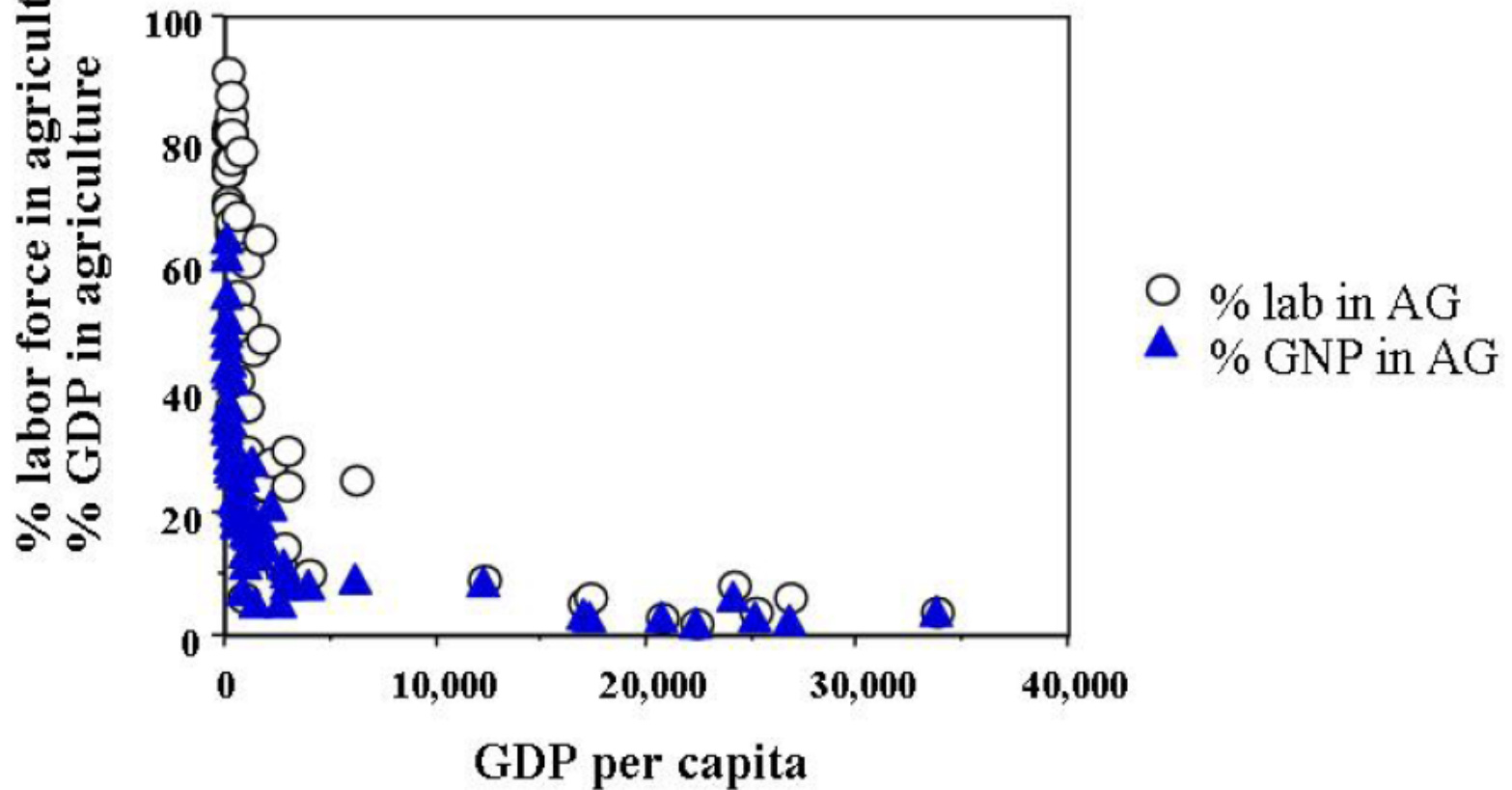
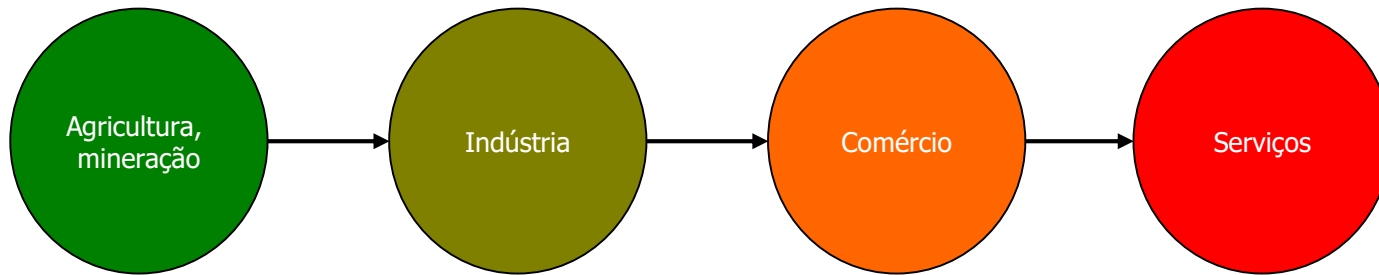


Figure 2. The international relationship between energy use (1000 million tonnes of oil equivalent) and GDP (million US dollars, 1998) (WRI, 2002).

Percentage of labor force and GDP in agriculture versus GDP per capita (US\$ - 1991)



Uso de recursos e agregação de valor



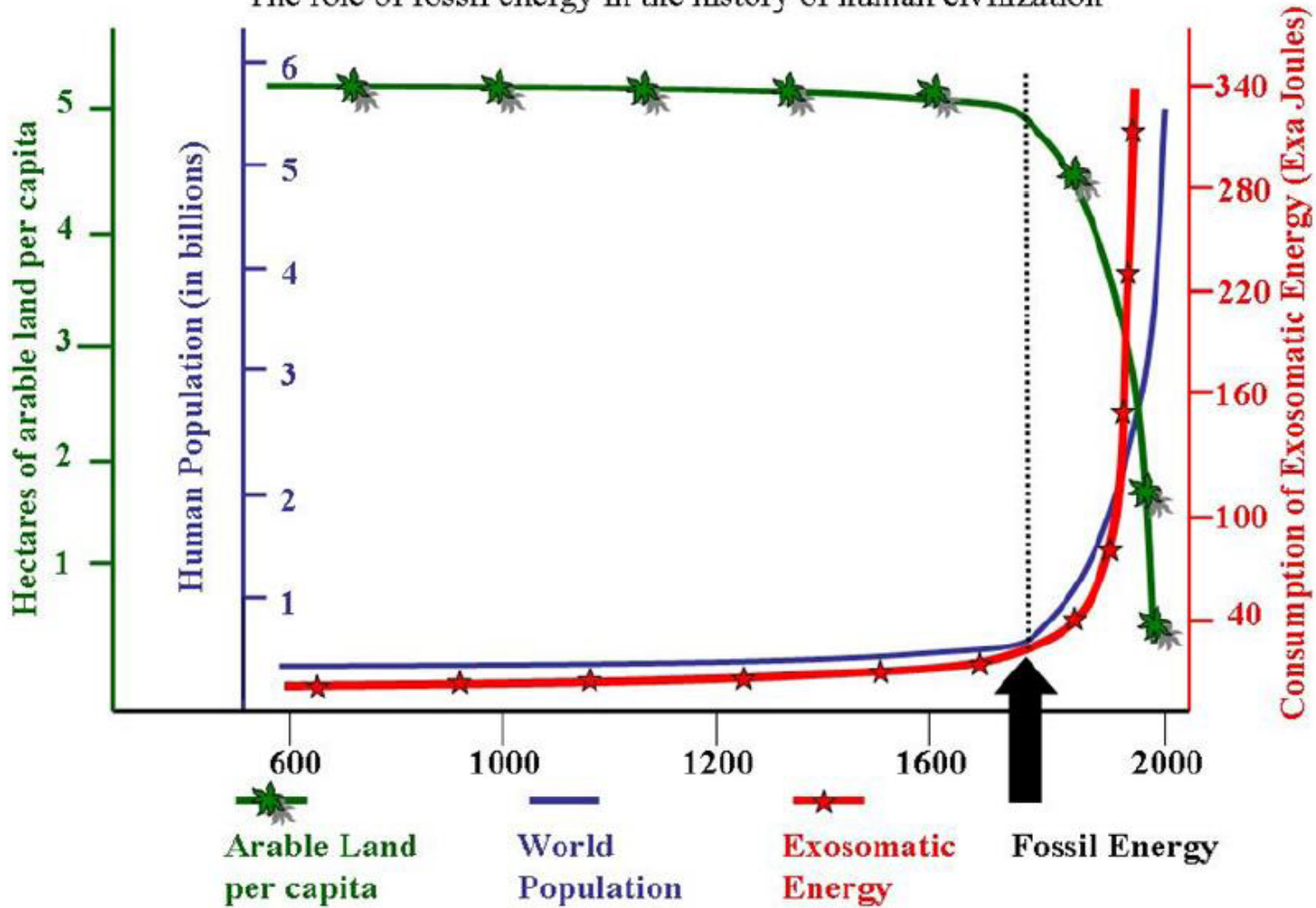
Número de pessoas, número de empresas, agregação de valor



Uso de insumos, uso de energia



The role of fossil energy in the history of human civilization



Economia e Recursos Naturais

Função de produção Cobb-Douglas

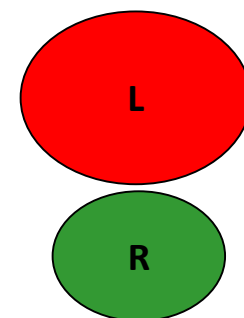
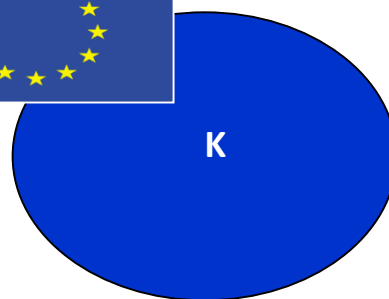
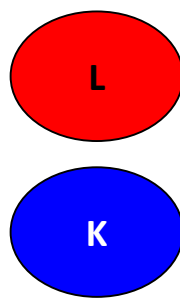
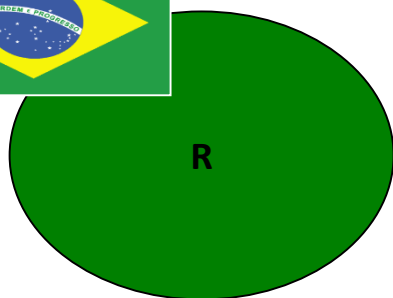
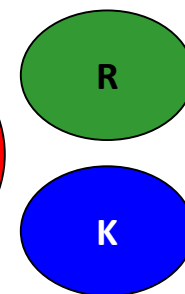
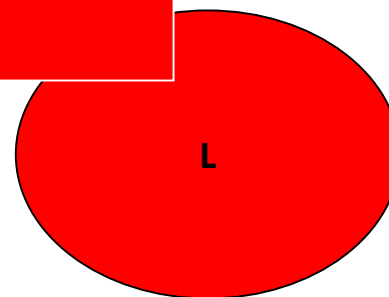
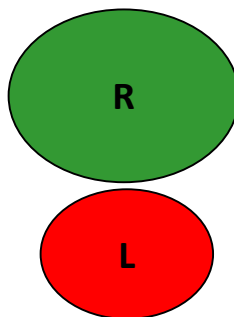
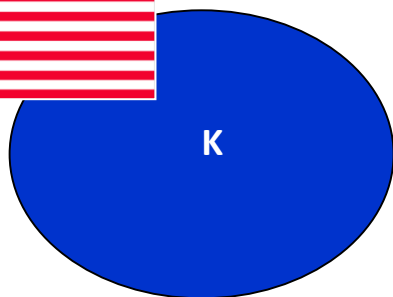
$$Q = K^{a1} L^{a2} R^{a3}$$

Q = produto
 K = capital
 R = recursos naturais
 L = mão-de-obra
 $a1, a2, a3$ = parâmetros fixos

$$\downarrow R^{a3} = \frac{Q_0}{\uparrow K^{a1} L_0^{a2}}$$

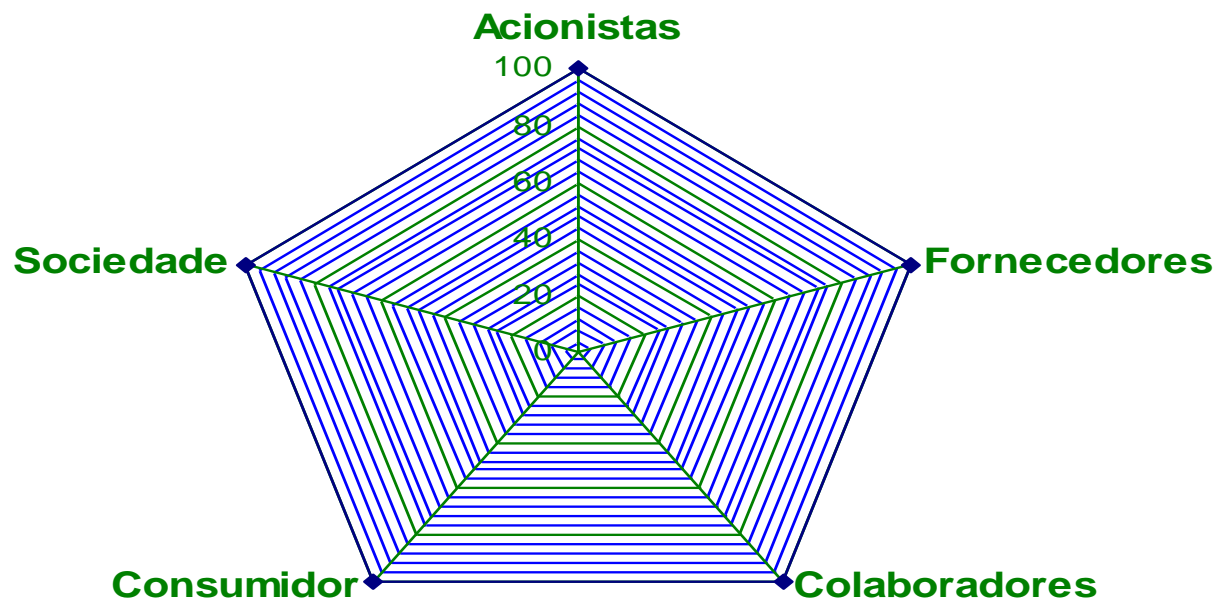
Romanelli (2009)

Economia e Uso de Recursos Naturais

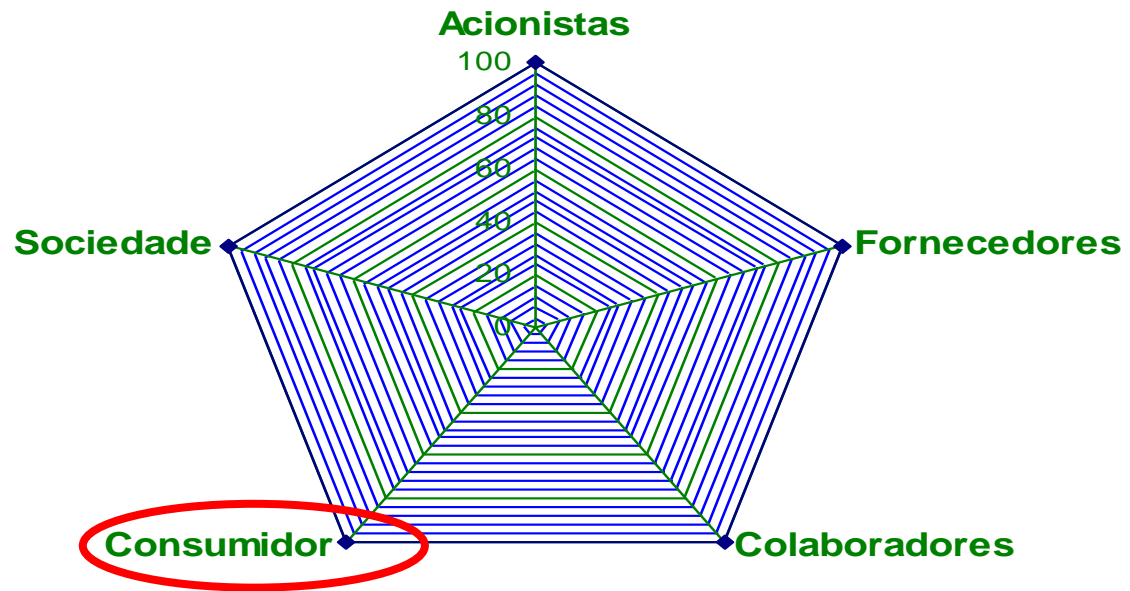


R = Recursos Naturais, L = Mão-de-obra, K = Capital

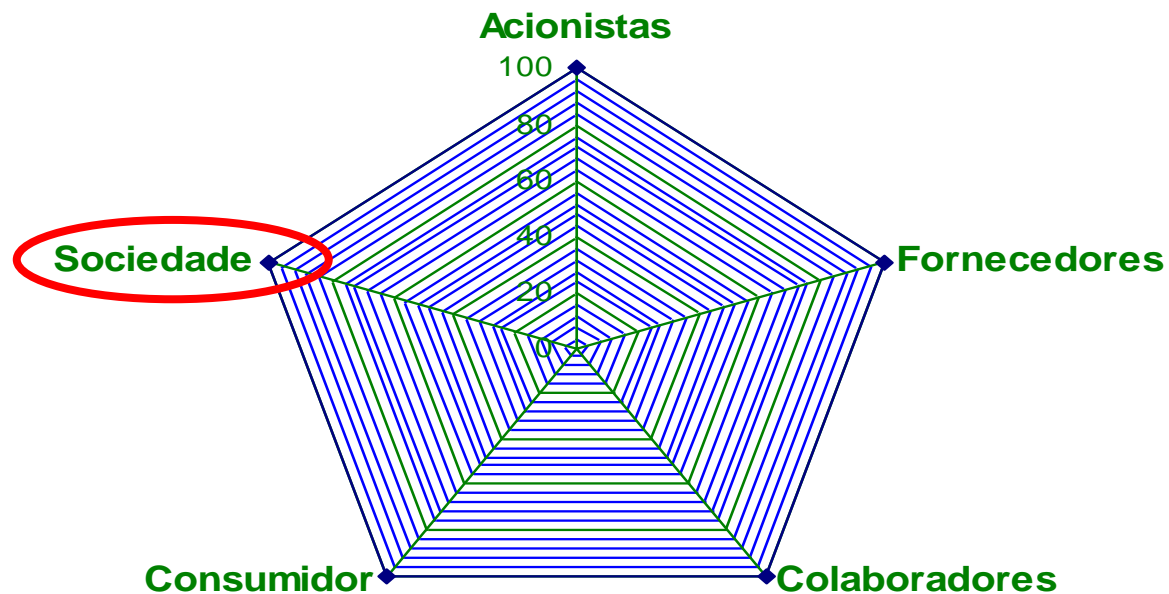
Stakeholders

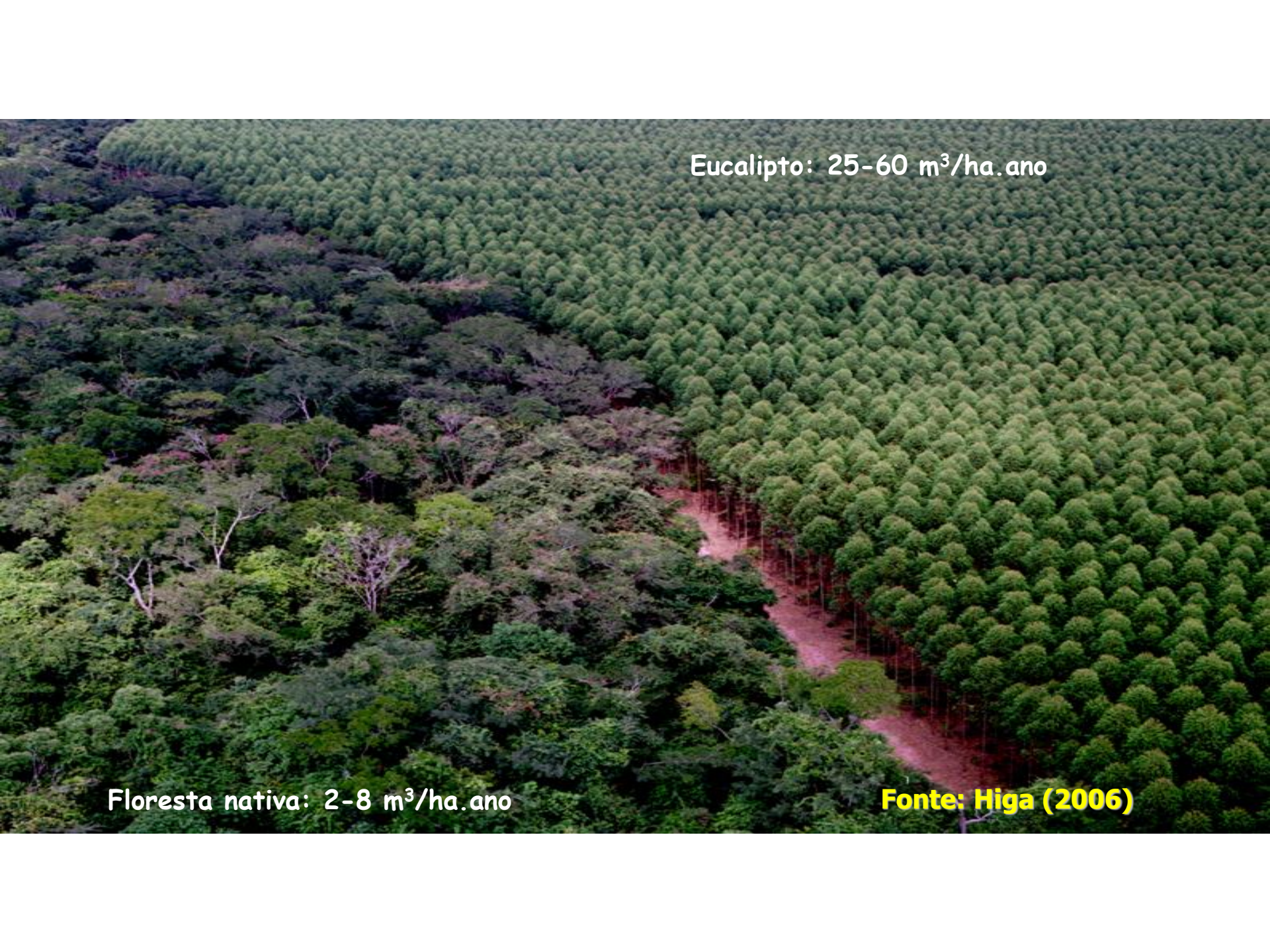


Qualidade do produto final



Qualidade no processo produtivo

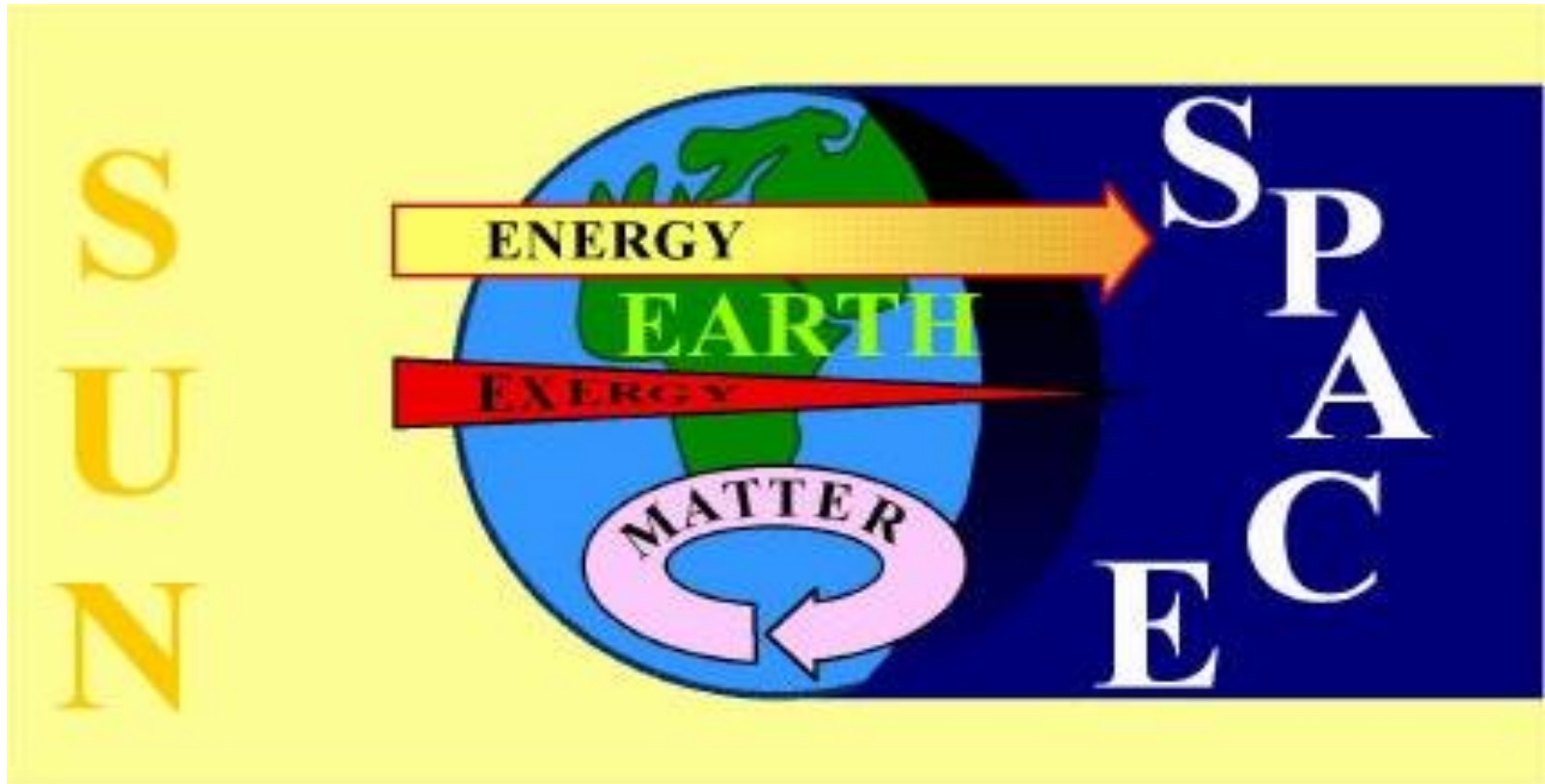




Eucalipto: 25-60 m³/ha.ano

Floresta nativa: 2-8 m³/ha.ano

Fonte: Higa (2006)

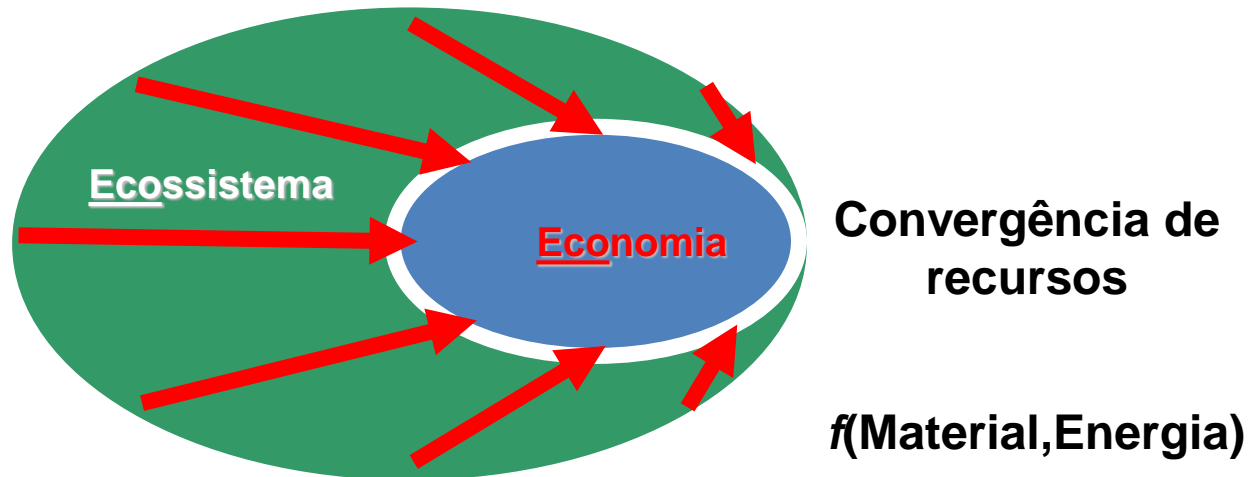


Wall & Cong (2001)

Economia e Recursos Naturais

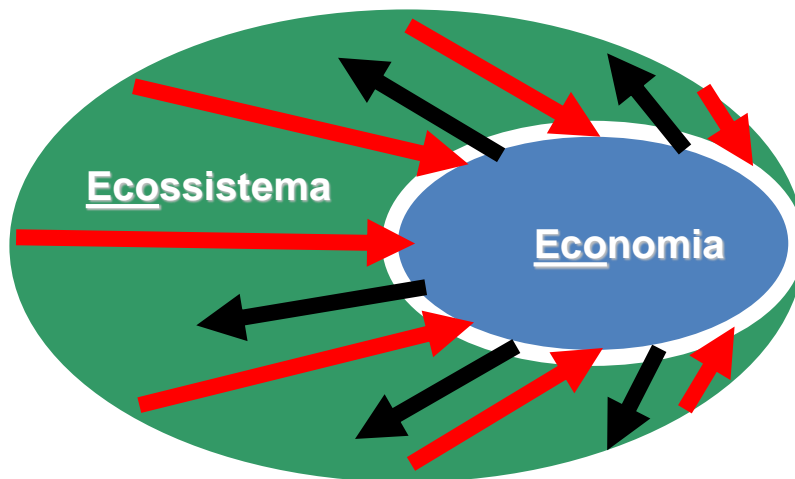
Os sistemas de produção são unidades de transformação

Fluxos de materiais e de energia



Economia e Recursos Naturais

Fluxos de materiais e de energia



Convergência de recursos com
baixa entropia

Resíduos
(alta entropia)

Importância

Incorporação
na biomassa

Incorporação
nos insumos

Table 1. Material flow of the production system and its energy evaluation

Inputs	Material flow		E_E^y MJ unit ⁻¹	Ener		%
	unit ha ⁻¹	unit		g yr ⁻¹	Priorizar Tomada de decisão	
Fuel	529.2	L	38.6 ¹	20.4	2.92	56.3
Fertilizer*	810.0	kg	28.5 ²	8.3	1.19	23.0
Herbicide	7.6	L	327.0 ³	2.5	0.35	6.9
Lime	1000.0	kg	1.7 ²	1.7	0.24	4.6
Machines	14.8	kg	68.9 ¹	1.0	0.15	2.8
Lubricant	22.8	L	38.6 ¹	0.9	0.13	2.4
Seedling	922.5	unit	0.8 ⁴	0.7	0.10	2.0
Labor	231.4	h	2.2 ⁵	0.5	0.07	1.4
Formicide	1.0	kg	184.7 ³	0.2	0.03	0.5
Water	5556.0	kg	0.0 ⁶	0.0	0.00	0.1
Total input				36.2	5.17	100.0
Output	Oferta de material ou energia					
Biomass	290.5	m ³	7425.0	2157.0	308.1	

Romanelli, T.L., Milan, M. Energy performance of a production system of eucalyptus. *Agriambi* 14 (2010) 896 - 903.

Determinação dos fluxos materiais

Geralmente negligenciada

Os resultados são comparados, impossibilitando a comparação dos métodos

Classificação fluxo de materiais?

Insumos Indiretamente aplicados

“prestam serviço”

- combustível
- mão-de-obra
- depreciação infra-estrutura

Insumos Diretamente aplicados

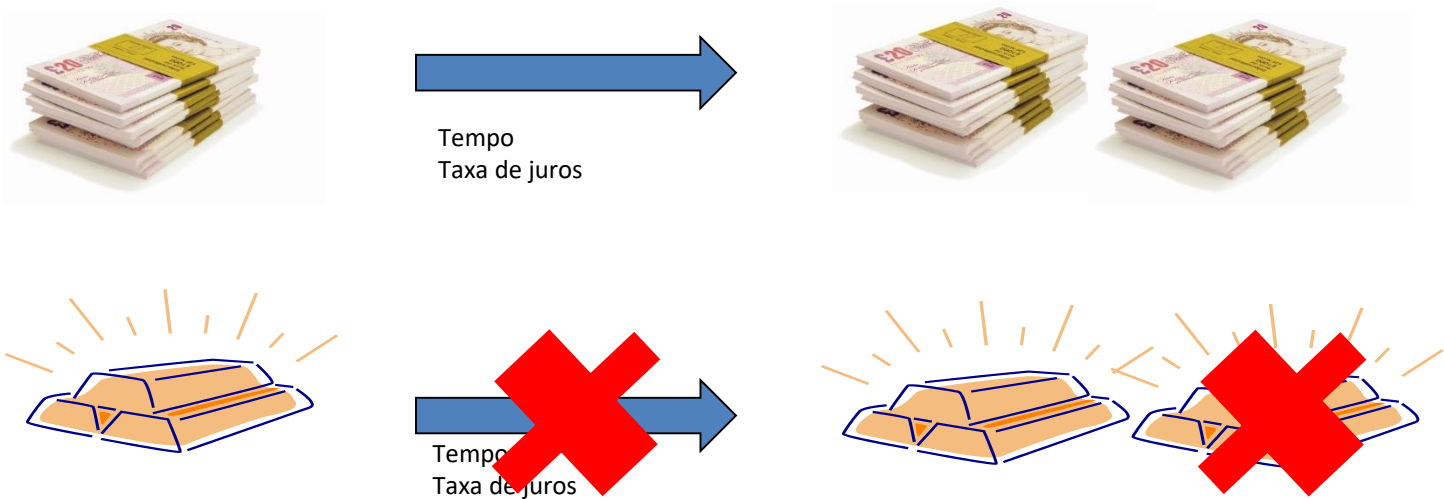
“compõem a produção”

- NPK, sementes, defensivos

Fluxo de materiais indiretos

Depreciação de máquinas

Lógica similar à econômica, porém respeita as restrições físicas



Monitoramento de sistemas de produção

O que está incorporado em 1 tonelada de soja?

TABLE 3. Material embodiment of soybeans in distinct scenarios.

Inputs	unit	RS	MS	GO	PR	MT unit Mg ⁻¹	BA	MG	MA	SP
Labor	h	2.6	2.2	2.2	1.8	2.1	2.3	1.9	1.7	1.3
Diesel	L	23.0	17.7	19.0	15.9	15.3	17.2	17.3	14.6	18.0
Mach. Depr.	kg	2.6	2.2	1.9	1.8	1.8	2.0	2.0	1.6	1.8
Limestone	kg	119.0	94.7	207.4	71.4	200.0	224.0	215.4	215.4	178.6
N	kg	0.0	0.0	0.0	0.0	0.0	0.0	3.1	3.1	1.8
P ₂ O ₅	kg	23.8	18.2	26.7	17.1	22.9	32.0	30.8	30.8	17.9
K ₂ O	kg	23.8	18.2	20.0	17.1	22.9	32.0	30.8	30.8	17.9
Seeds	kg	31.0	26.5	25.9	23.2	21.4	26.0	23.1	25.0	26.8
Seed treatment	L	0.5	0.6	0.4	0.5	0.6	0.8	0.5	0.8	0.8
Acaricide	L	0.2	0.2	0.1	0.0	0.1	0.1	0.4	0.4	0.1
Fungicide	L	0.6	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.4
Herbicide	L	1.5	2.3	2.0	1.9	1.8	2.0	1.7	1.3	1.4
Insecticide	L	0.3	0.2	0.4	0.8	0.2	0.2	0.2	0.1	0.8
Other chemicals	L	0.3	0.3	0.3	0.4	0.3	0.3	0.3	0.3	1.8

Thiago L. Romanelli, Hudson de S. Nardi, Filipe A. Saad

Eng. Agríc., Jaboticabal, v.32, n.2, p.261-270, mar./abr. 2012

GESTÃO DE SISTEMAS DE PRODUÇÃO

Fontes de bioenergia

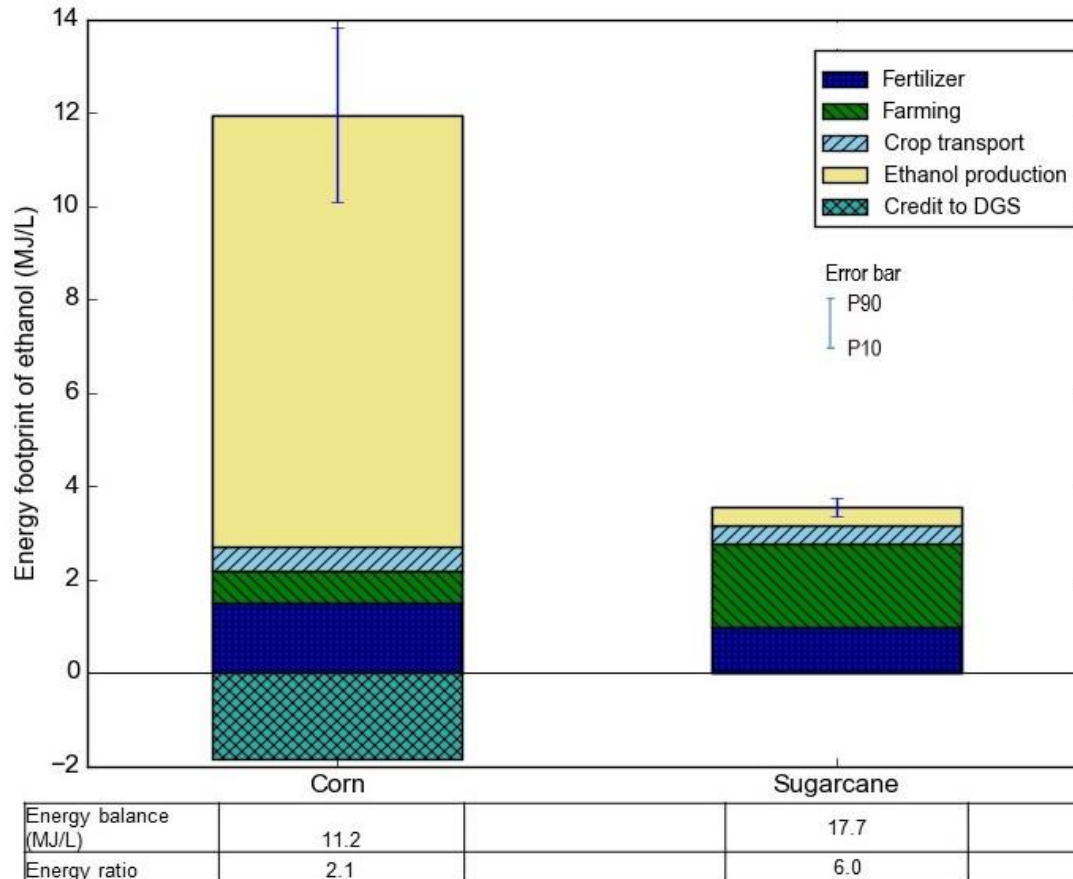


Figure 3. The energy footprint, overall energy balance, and fossil energy ratio of bioethanol from corn in the US and sugarcane in Brazil.

Fonte de óleo vegetal

Table 2. Energy input and output (GJ ha⁻¹), energy balance (EB, GJ ha⁻¹) and energy return on investment (EROI, GJ ha⁻¹) from all components used for Jatropha production.

		Irrigated				Rainfed			
		N0	N50	N100	N150	N0	N50	N100	N150
Input	Fuel	17.71	17.71	17.71	17.71	17.71	17.71	17.71	17.71
	Electric energy	2.11	2.11	2.11	2.11	-	-	-	-
	Labor	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59
	Machinery	3.24	3.24	3.24	3.24	3.24	3.24	3.24	3.24
	Fertilizers and Chemicals	3.19	4.93	6.66	8.39	3.19	4.93	6.66	8.39
	Irrigation system	4.44	4.44	4.44	4.44	-	-	-	-
	Implantation	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
Total input		32.28	34.01	35.74	37.48	25.71	27.45	29.18	30.92
Output	Jatropha fruit	20.83	30.85	34.34	39.14	5.48	18.58	17.23	21.26
	Residues	2.08	3.08	3.43	3.91	0.55	1.86	1.72	2.13
	Total output	22.91	33.93	37.77	43.06	6.02	20.44	18.95	23.39
EB	Without residues credits	-11.45	-3.16	-1.41	1.66	-20.23	-8.87	-11.95	-9.65
	With residues credits	-9.36	-0.08	2.03	5.57	-19.69	-7.01	-10.23	-7.52
EROI	Without residues credits	0.65	0.91	0.96	1.04	0.21	0.68	0.59	0.69
	With residues credits	0.71	0.99	1.06	1.15	0.23	0.74	0.65	0.76

N0 (0% N), N50 (50% N), N100 (100% N) and N150 (150% N).

Santos, O.N.A.; Andrade, I.P.S.; Lena, B.P.; Folegatti, M.V., Diotto, A.V., **Romanelli, T.L.** Impact of irrigation and nitrogen fertilization on the energy balance and energy return on investment of Jatropha production. **Rev. Bras. Ag. Irrigada**, 11 (2017) 1738 – 1746.

Comparação - Amiláceas

Table 2 – Direct and indirect energy embodied for starch crops in Brazil.

Culture	Maize		Cassava		Potato		Rice	
	GJ ha ⁻¹	%	GJ ha ⁻¹	%	GJ ha ⁻¹	%	GJ ha ⁻¹	%
Indirect inputs	2.34	15	4.82	44	8.53	10	7.27	44
Diesel	2.05	13	3.24	29	7.03	9	6.02	36
Machinery	0.29	2	0.61	6	1.31	2	1.15	7
Labor	< 0.01	0	0.97	0.09	0.18	0	0.10	0
Electricity	-	-	-	-	5.30	7	-	-
Direct inputs	13.15	85	6.21	56	67.65	83	9.27	56
Fertilizers	8.75	56	4.96	45	16.09	20	5.29	32
Seeds	0.41	3	1.05	9	26.52	33	3.06	18
Chemicals	3.99	26	0.21	2	25.04	31	0.93	6
Total (GJ ha ⁻¹)	15.49		11.03		81.47		16.54	
Yield (Mg ha ⁻¹)	8.80		22.00		30.00		7.00	
Carbohydrate content (%)	62		34		16		64	
Embodied energy (MJ Mg ⁻¹)	1,760.15		501.38		2,715.65		2,363.26	
	2,838.95		1,474.64		16,972.79		3,692.60	

Veiga, J.P.S.; **Romanelli, T.L.**; Gimenez, L.M.; Busato, P.; Milan, M. Energy embodiment in Brazilian agriculture: an overview of 23 crops. **Scientia Agricola**, 72 (2015) 471 - 477.

Eficiência de campo

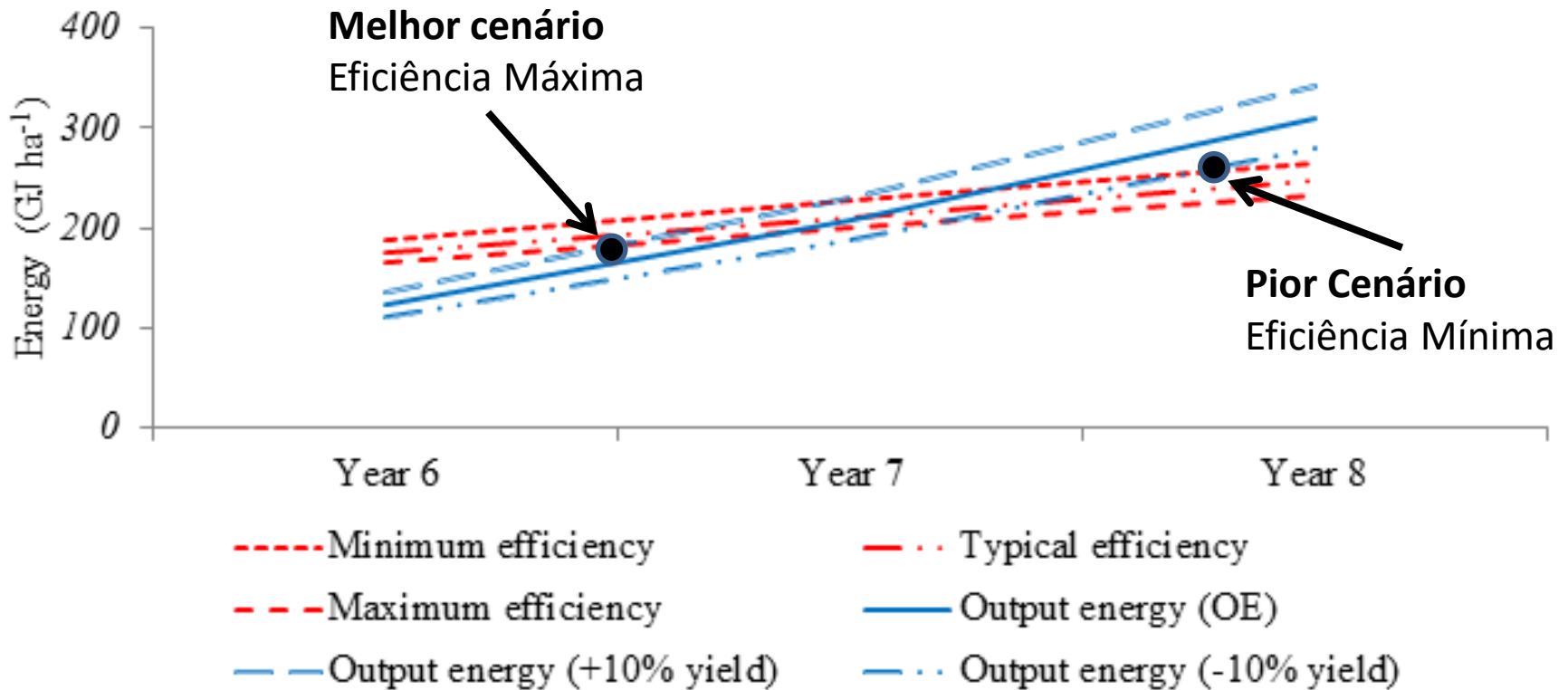


Figura baseada em dados da Tabela 7 - Energy demand for citrus production under field efficiency scenarios for mechanized operations.

IMPACTOS DA ADOÇÃO DE TECNOLOGIA NA EFICIÊNCIA ENERGÉTICA

Agricultura de Precisão

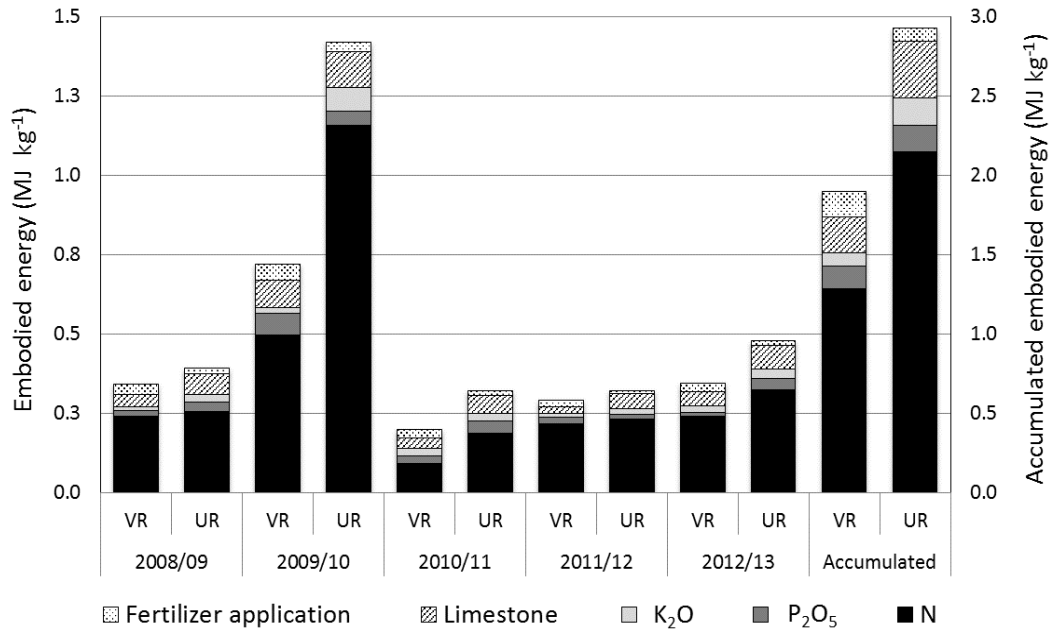


Figure 1. Embodied fertilizer energy in uniform rate (UR) and variable rate (VR) treatments in grove 1

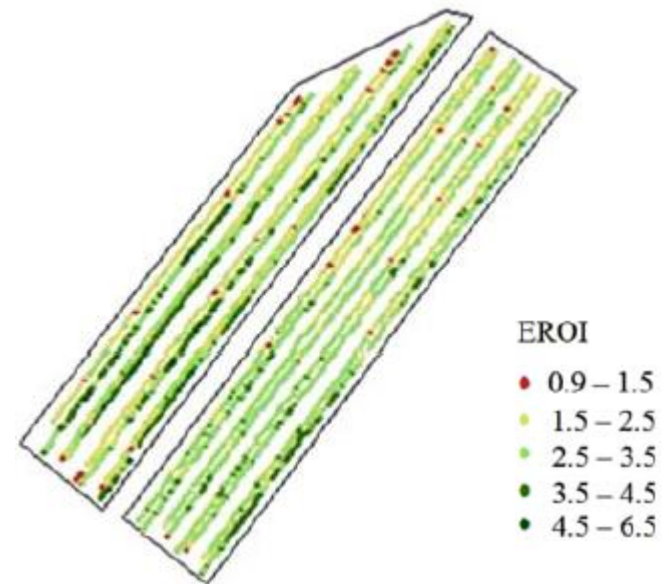


Figure 2 Maps of energy indicators on variable and fixed nitrogen fertilization intercalated strips

Colaço, A.F.; Pagliuca, L.G.; **Romanelli, T.L.**; Molin, J.P. Economic viability, energy and nutrient balance of site-specific nutrient management for citrus in Brazil. **Precision Agriculture** (em revisão PRAG-D-18-00251)

Colaço, A.F., Povh, F.P.; Molin, J.P., **Romanelli, T.L.** Energy assessment for variable rate nitrogen application. **CIGR Journal**, 14 (2012) 85-90.

Planejamento de Percurso

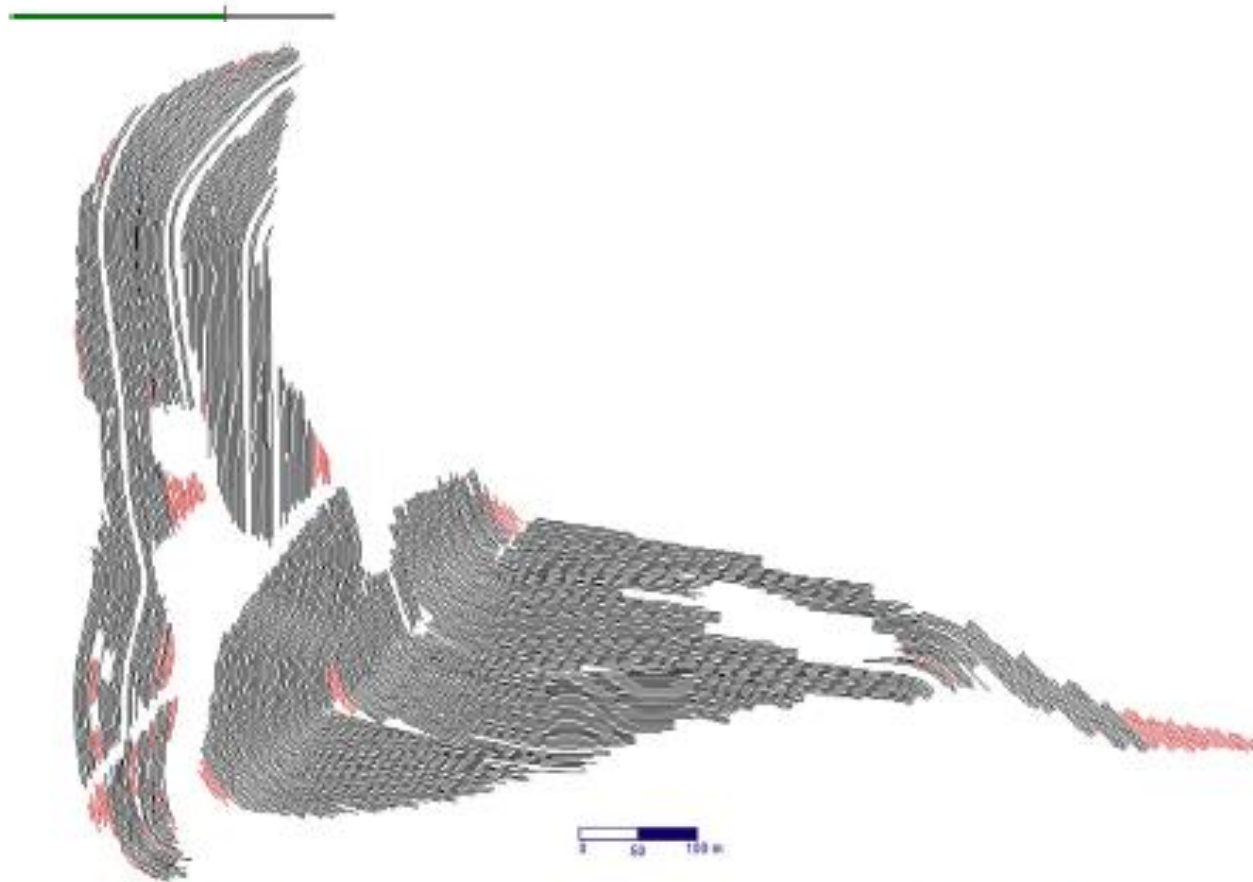
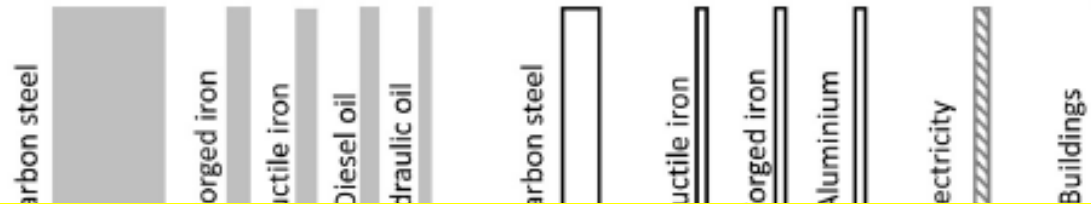


Fig. 13 – Spatial pre-planned tracks for sugarcane rows. Rows in red are too short to pay for the cost of the headland manoeuvre. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

ENERGIA INCORPORADA NA INFRAESTRUTURA

Colhedora de cana-de-açúcar



Colhedora de cana: 204 MJ kg⁻¹

Berry e Fels (1972) baseados na indústria automotiva dos anos 1960: 81,2 MJ kg⁻¹

Deleage et al. (1979) baseado em materiais ferrosos de tratores: 75,0 MJ kg⁻¹

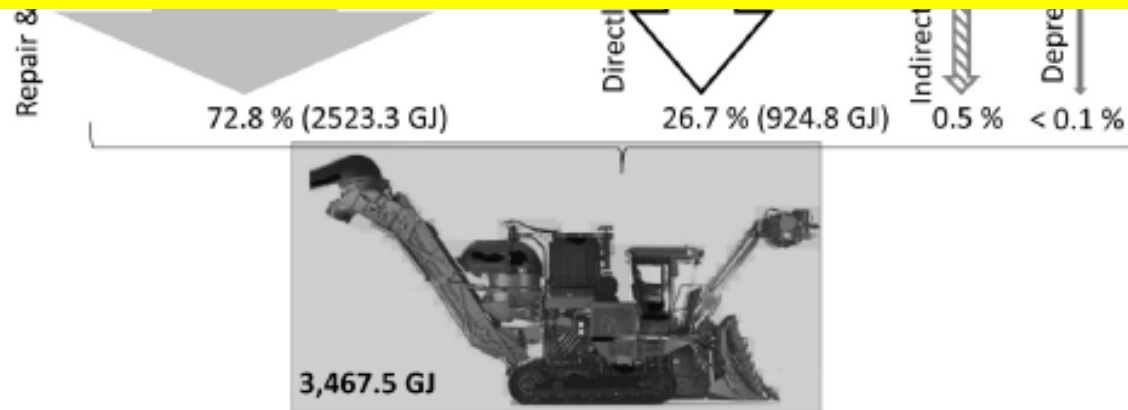


Fig. 3 – Embodied energy composition of sugarcane harvester with metal tracks.

Tratores

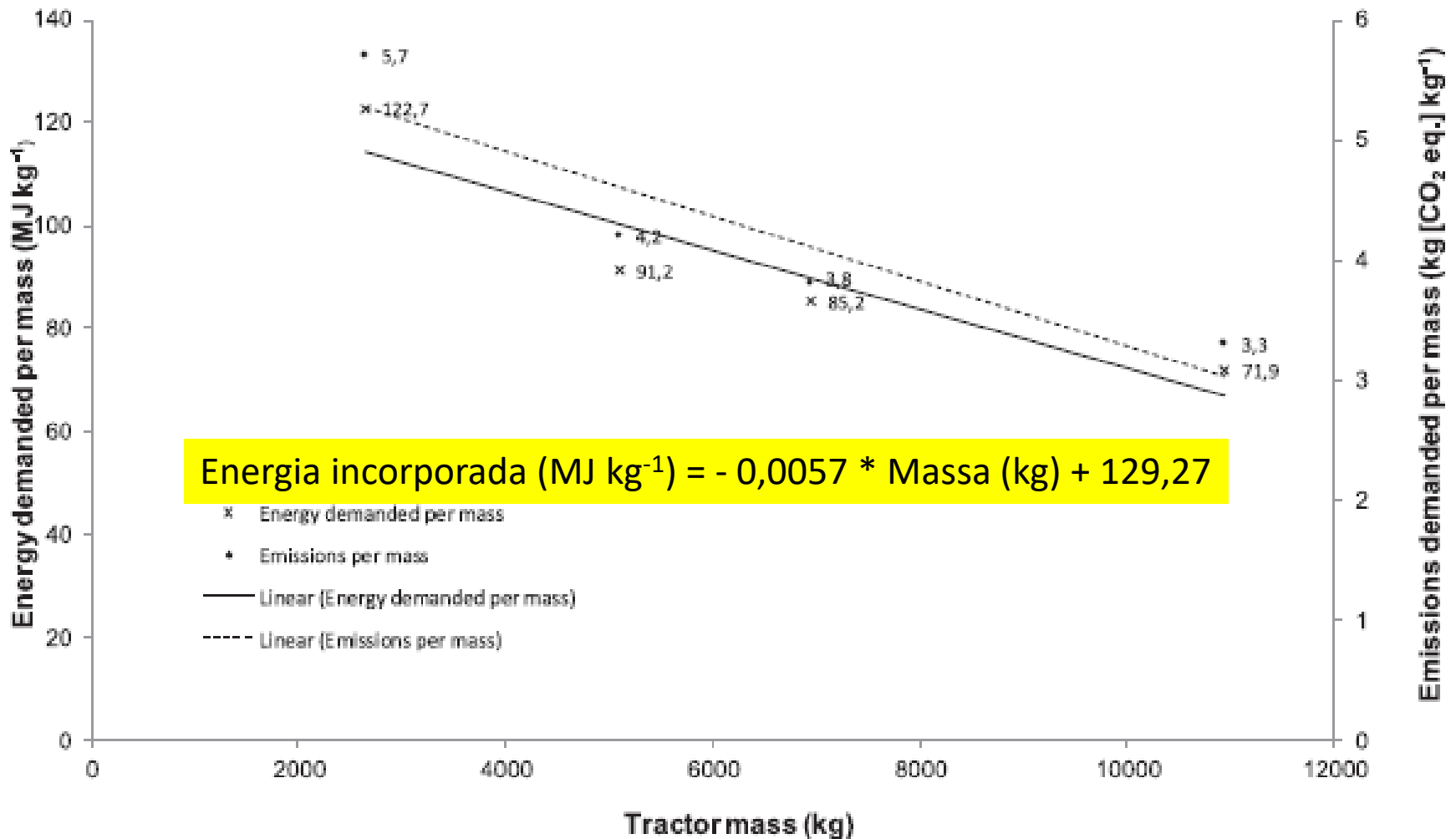
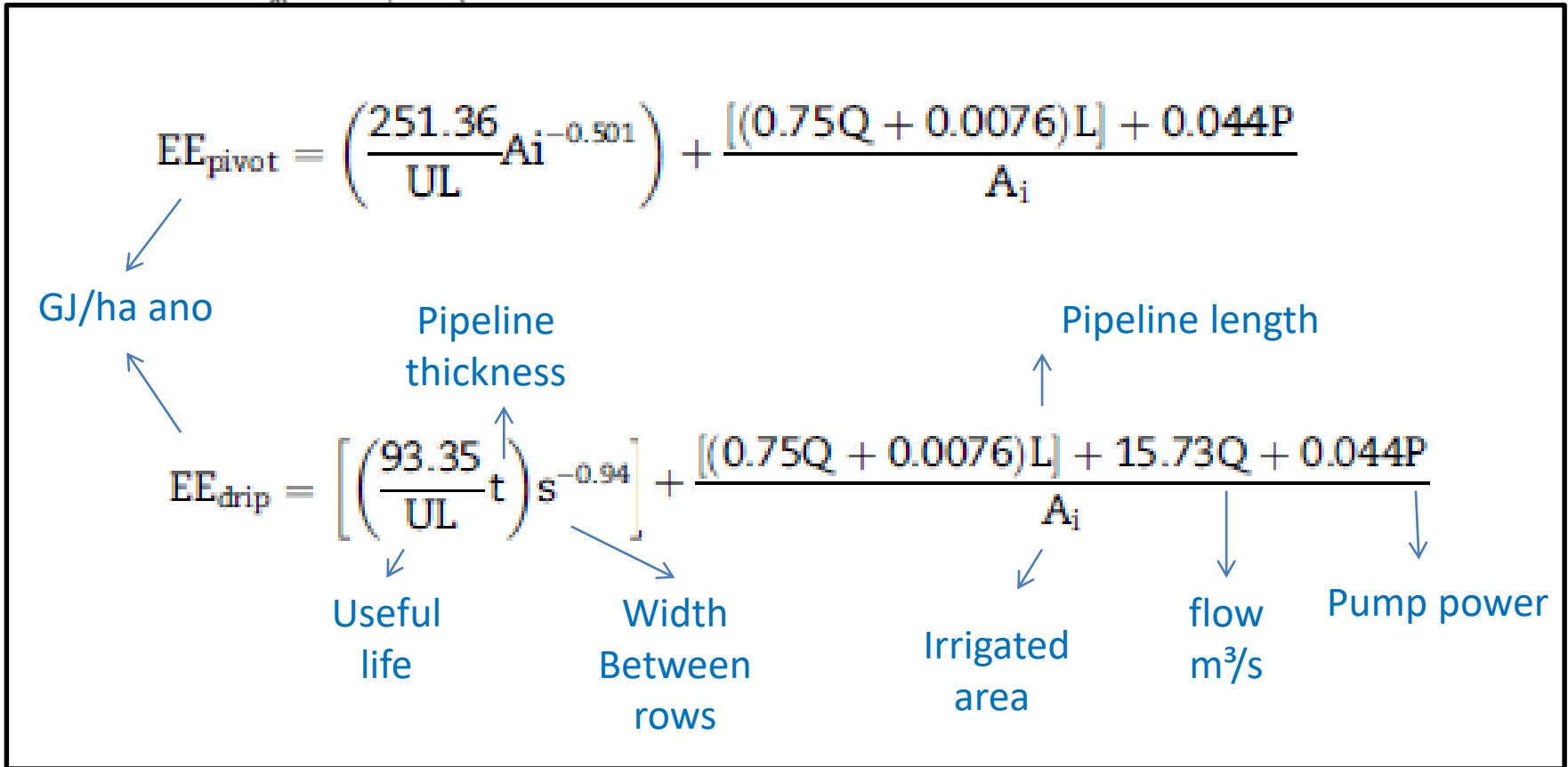
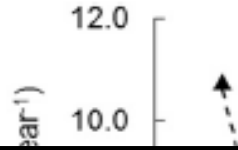


Fig. 6 – Tendency of energy demanded by engine power and mass for tractors.

Irrigação



years; (Δ) 20 years; (●) 25 years; and (○) 30 years.

COMPLEMENTO À OUTRAS ÁREAS DO CONHECIMENTO

Microeconomia

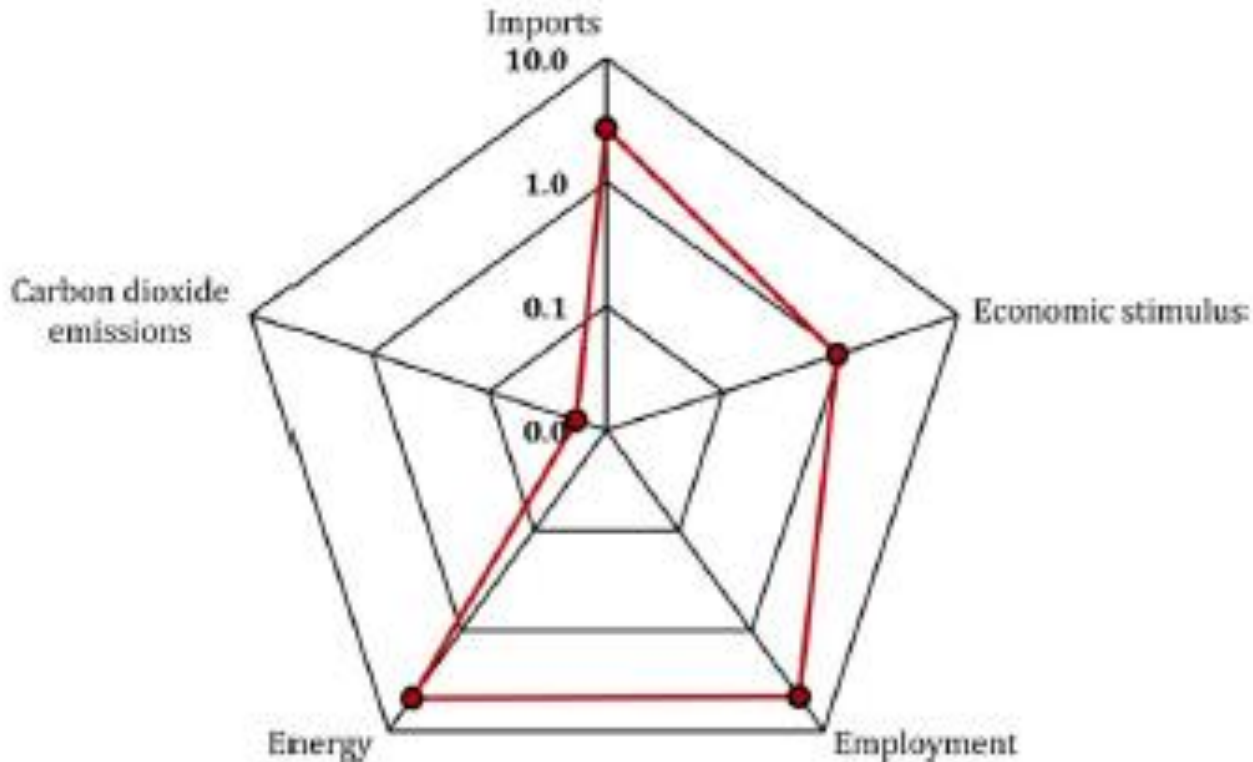


Fig. 3. Spider diagram based on Table 1. The scale is logarithmic. The line that forms the polygon in the centre ($n = 1$) signifies the cattle and other live animals sector. The position of the red line inside $n = 1$ represents a better performance than the cattle and other livestock sector, whereas a position outside $n = 1$ is worse than the cattle and other livestock sector. The case shown is for Owner produced sugarcane.

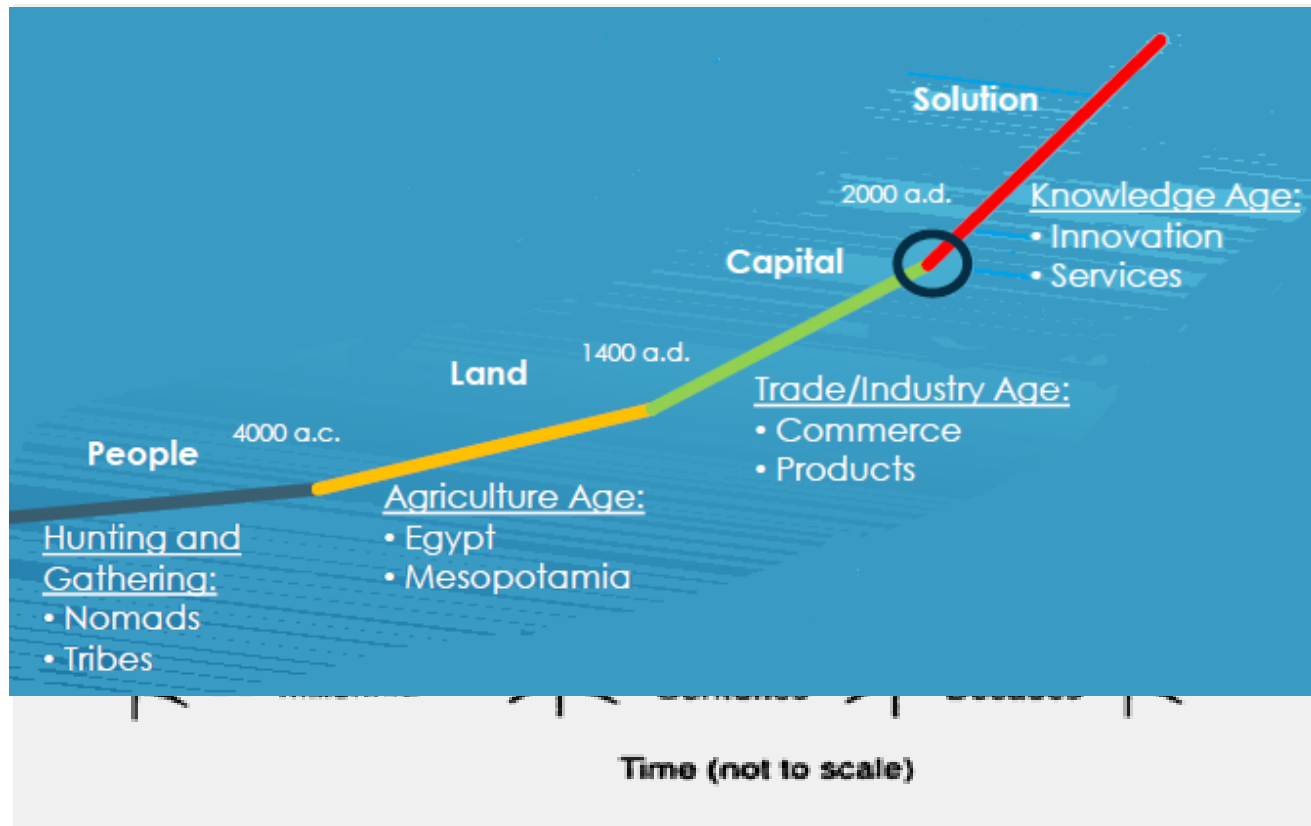
Agroindústria

Table 1 - Compared biodiesel production processes.

	ROE ^a	ROM ^b	MQ ^c	ME ^d	MEC ^d
Alcohol used	Ethanol	Methanol	Ethanol	Ethanol	Ethanol
Oil:alcohol ratio (mol mol ⁻¹)	1:12	1:6	1:12	1:4.5	1:4.5
Catalyst used	NaOH	NaOH	NaOH	Enzymes ^e	Enzymes ^e
Mass fraction of catalyst on oil	0.3 %	1.0 %	0.67 %	9.5 %	9.5 %
Temperature (°C)	70	60	30	40	40
Mass fraction of co-solvent on oil	-	-	-	-	5 % tert-butanol
Alkyl esters mass fraction yield	97.2 %	90.0 %	97.2 %	85.4 %	93.0 %
Reaction time (h)	2	1	1	24	24
Washing number	6	10	5	-	-
Washing water temperature (°C)	80	50	80	-	-
Alcohol evaporation	Yes	No	Yes	Yes	Yes

Sangaletti-Gerhard, N.; **Romanelli, T.L.**; Vieira, T.M.F.S.; Navia, R.;Regitano-d'Arce, M.A.B. Energy flow in the soybean biodiesel production chain using ethanol as solvent extraction of oil from soybeans. **Biomass and Bioenergy**, 66 (2014) 39-48.

Era da Informação



Futuro

- **AI-based:** decision support systems, precision agriculture, agricultural optimization management
- **Smart sensors** and **Internet of Things**
- Agricultural **robotics** and **automation** equipment
- Agricultural **knowledge-based** systems
- Intelligent **interfaces** and **human-machine** interaction
- **Machine learning** and **pattern recognition**
- Systems **modeling** and **analysis**
- **Intelligent systems** for animal feeding
- **Remote sensing** in agriculture
- **Big Data** and **Cloud Computing**
- **Crop Phenotyping** and analysis
- **Automatic navigation** and **self-driving** technology
- **Computational intelligence** in agriculture, food and biosystems



Suporte para Gestão Tomada de Decisão

Informação combinada com
experiencia e opiniões

Conhecimento

Dados colocados num
determinado contexto

Informação

Fatos ou
observações

Dados

Tian et al. (2009); Davenport (1998); Angeloni (2003)