“Center for BioEnergy Sustainability CEBS”

Modeling LUC due to sugarcane expansion

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1. Introduction to the BLUM model
2. Coupling GIS data and economic models
3. Dealing with technology

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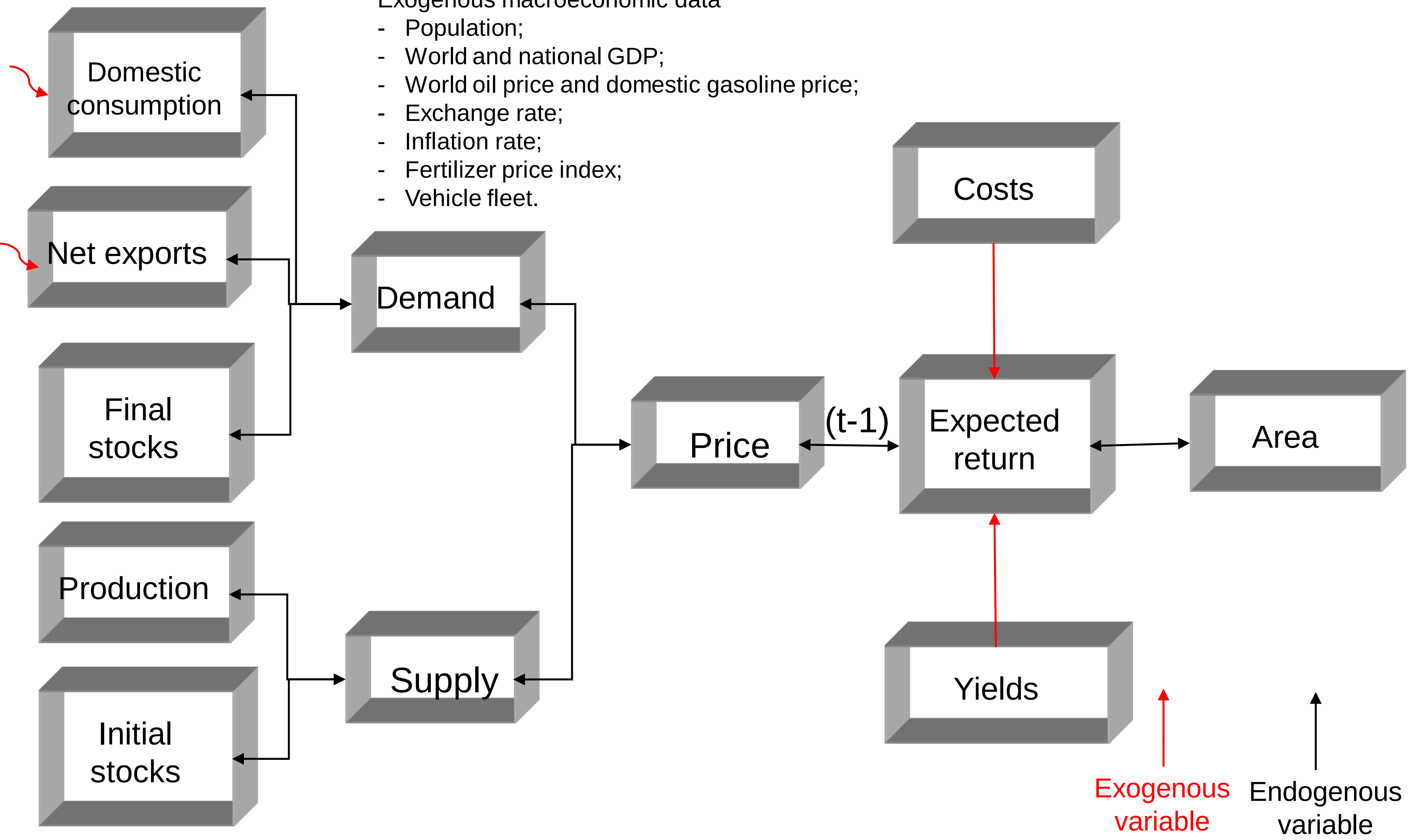
The BLUM model

- Joint partnership between ICONE and FAPRI-CARD (since 2007)
- "Spreadsheet" model (runs in Excel)

- BLUM model has been used in:
  - ✓ FAPRI US and world outlook
  - ✓ Regulatory Impact Analysis – RFS2 (EPA)
  - ✓ Brazilian Low Carbon Study (World Bank)
  - ✓ Brazilian Agribusiness Outlook 2022
  - ✓ (…).

Structure of the Supply and Demand Section

Exogenous macroeconomic data
- Population;
- World and national GDP;
- World oil price and domestic gasoline price;
- Exchange rate;
- Inflation rate;
- Fertilizer price index;
- Vehicle fleet.



Source: ICONE.

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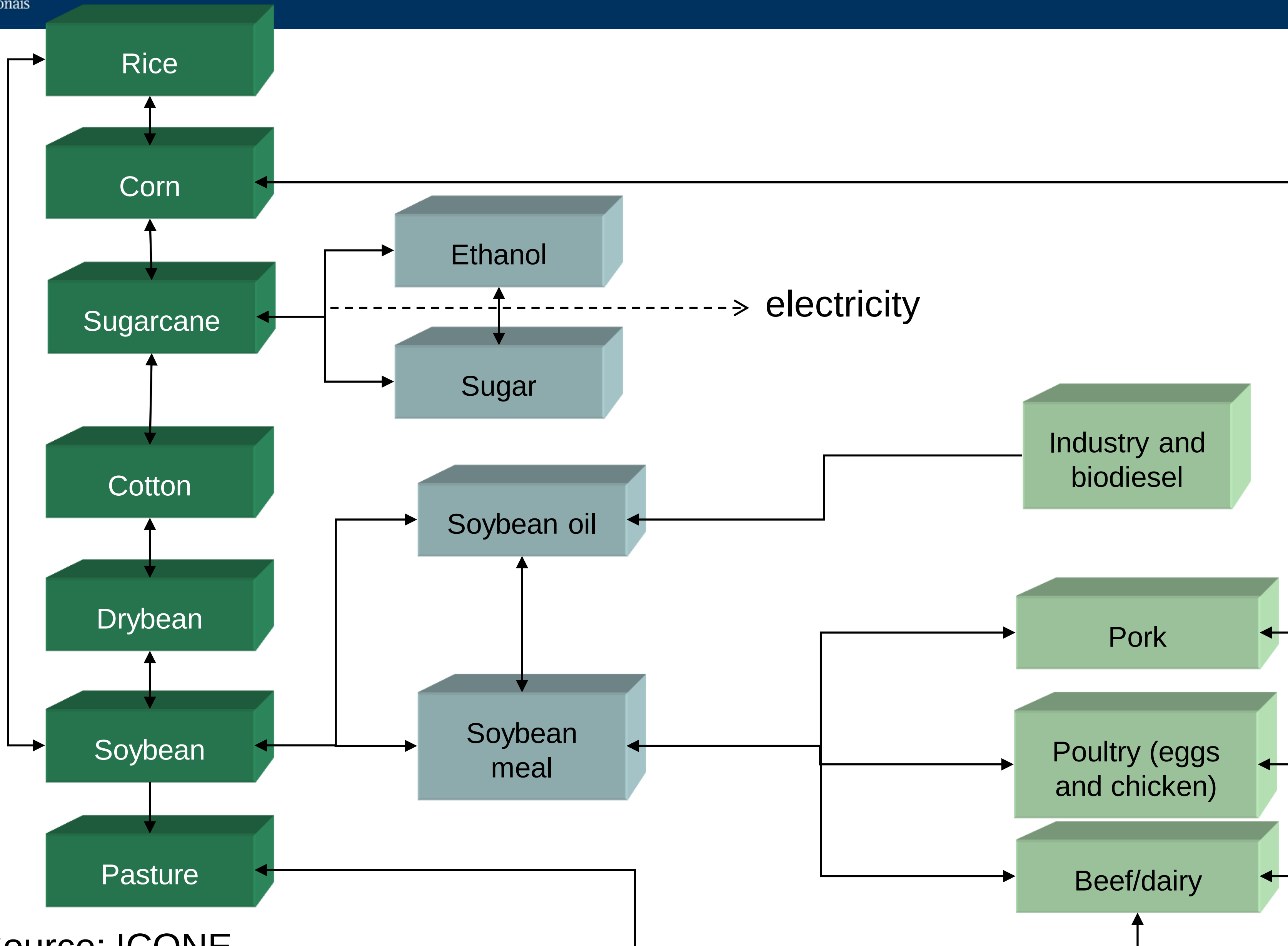
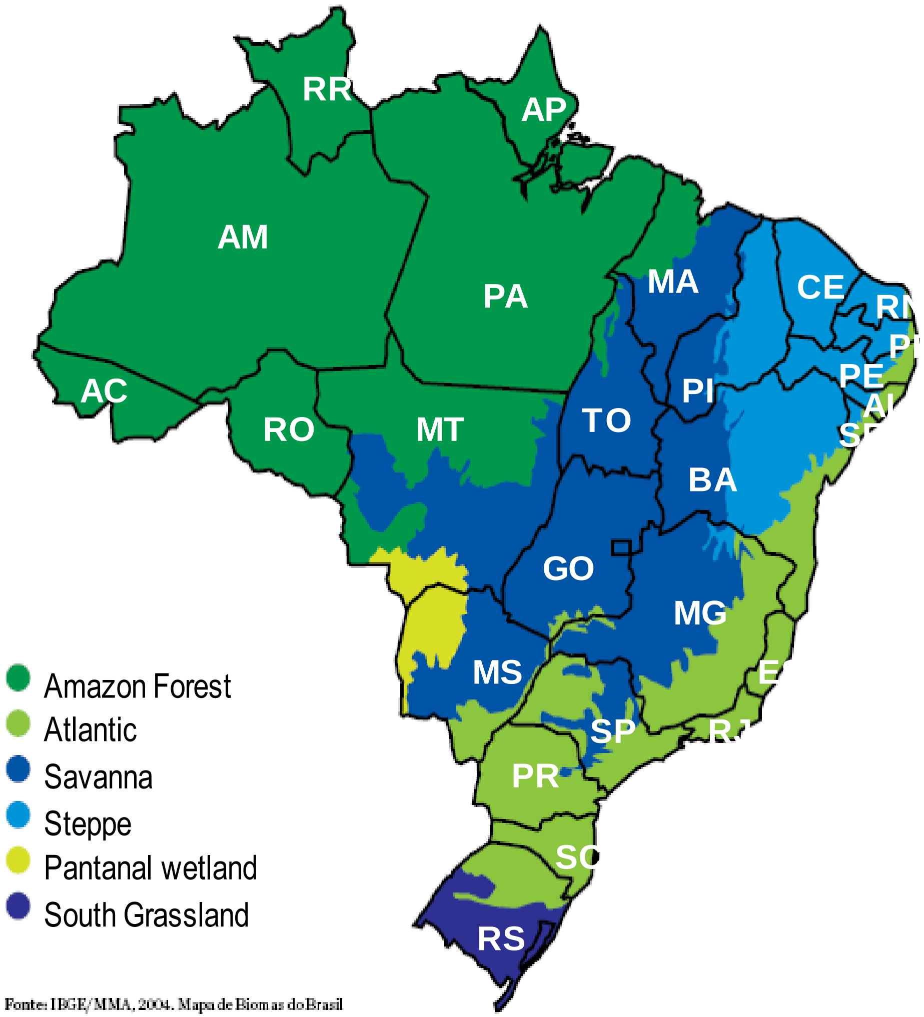
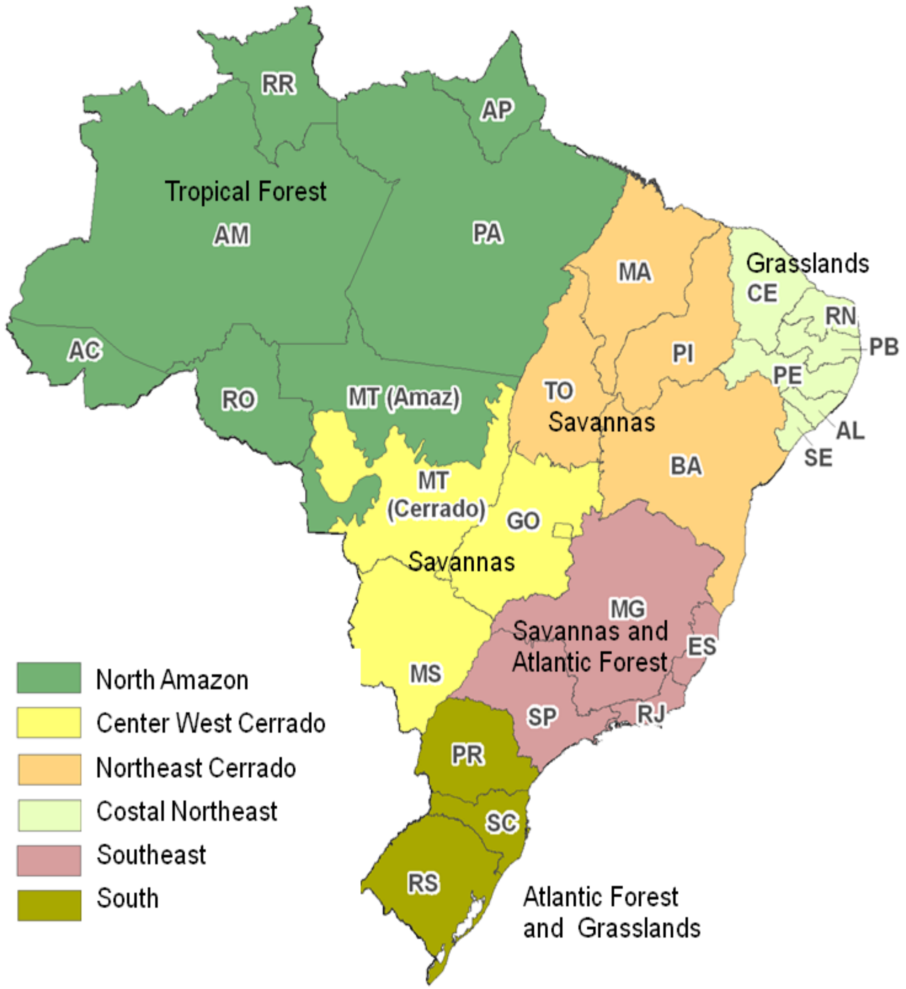
Activities Covered by the Model



Source: ICONE

Brazilian Biomes and BLUM Regions





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Matching theory with data: GIS inputs for economic models

Driver of deforestation in the Amazon: Soybean Moratorium Project

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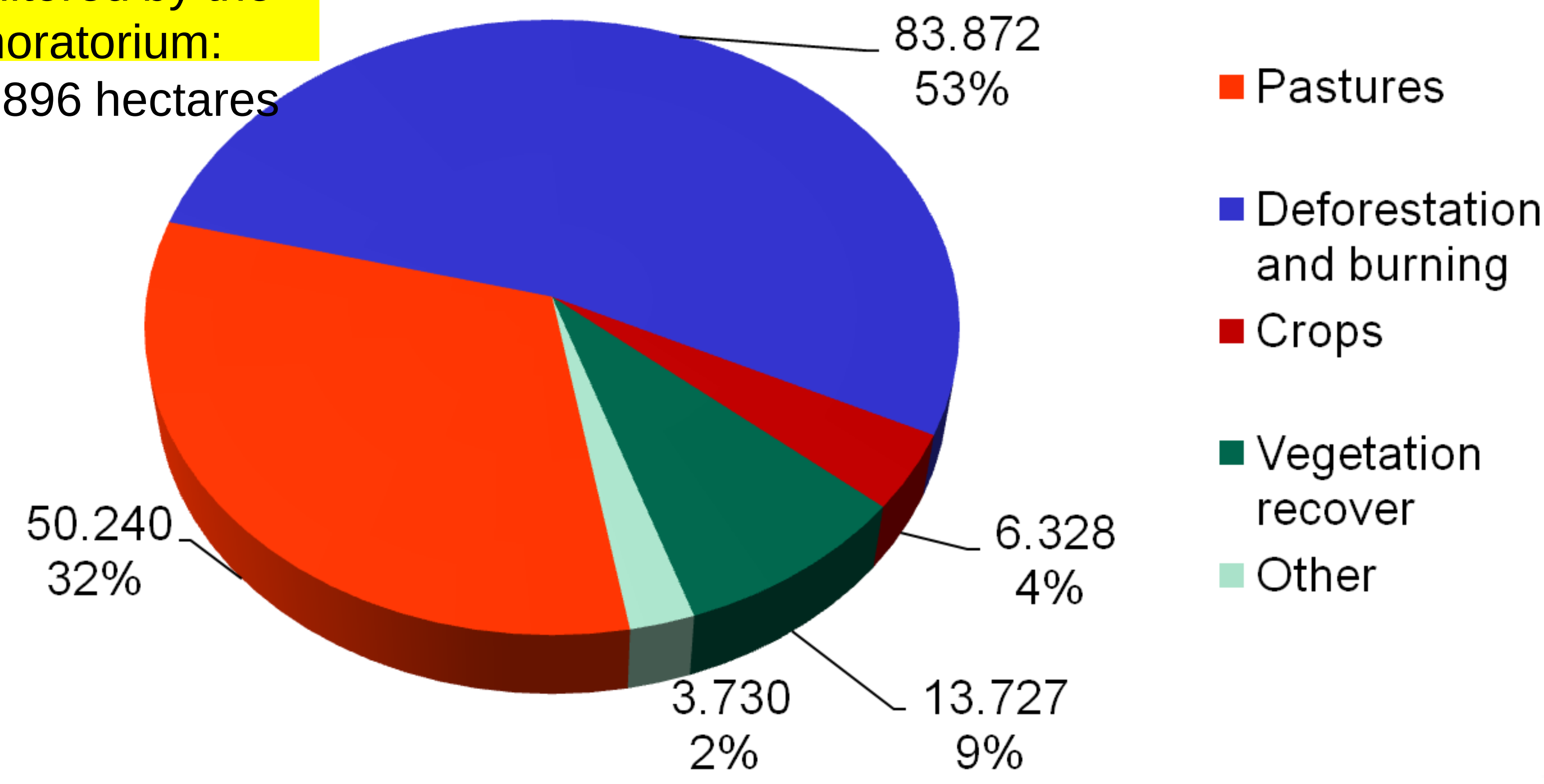
Amazon Biome: Deforestated Area under Monitoring from 2006 to 2008 by Land Use Classes (hectares)

Total area cleared monitored by the moratorium: 157,896 hectares



Source: Abiove e Globalsat (www.abiove.com.br).

INPE

Deforestation on the Cerrado Biome (Brazilian savannas)

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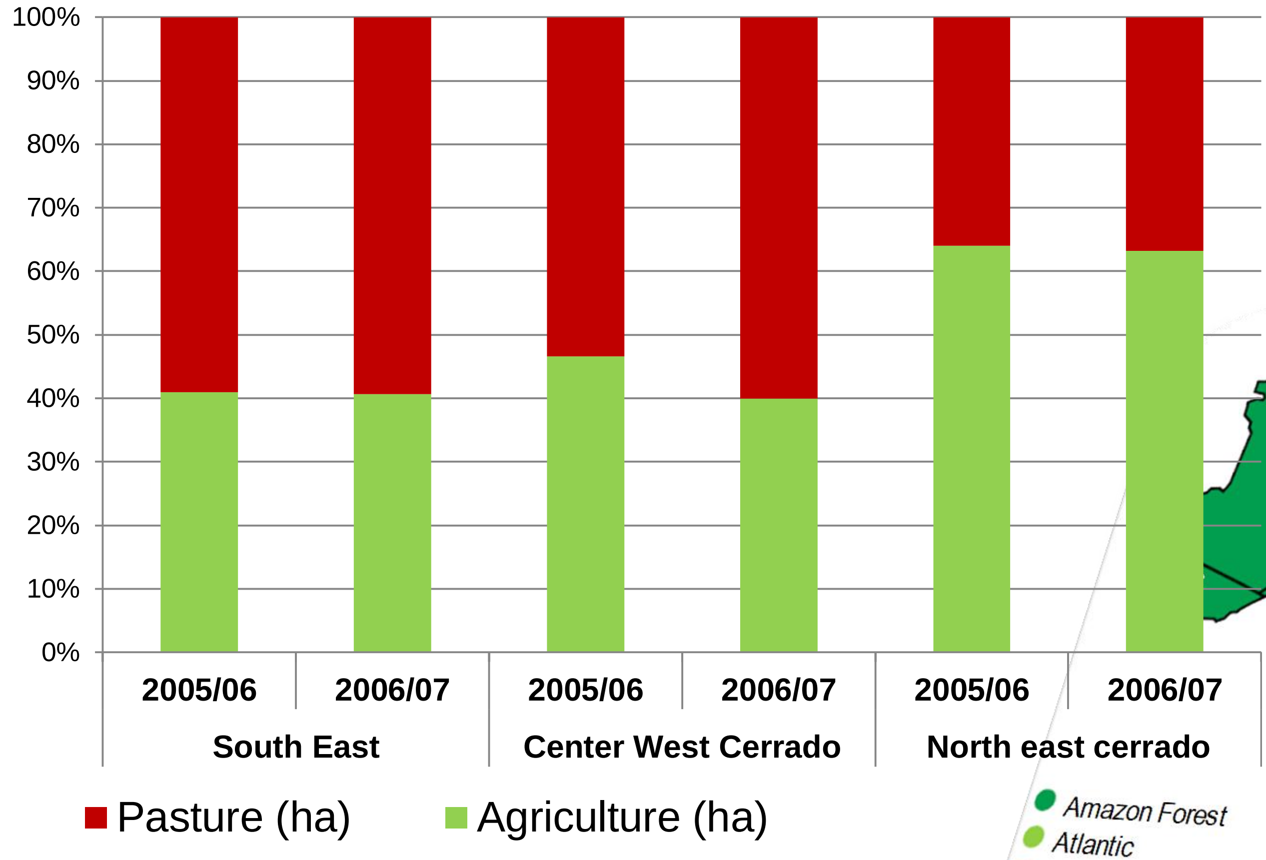
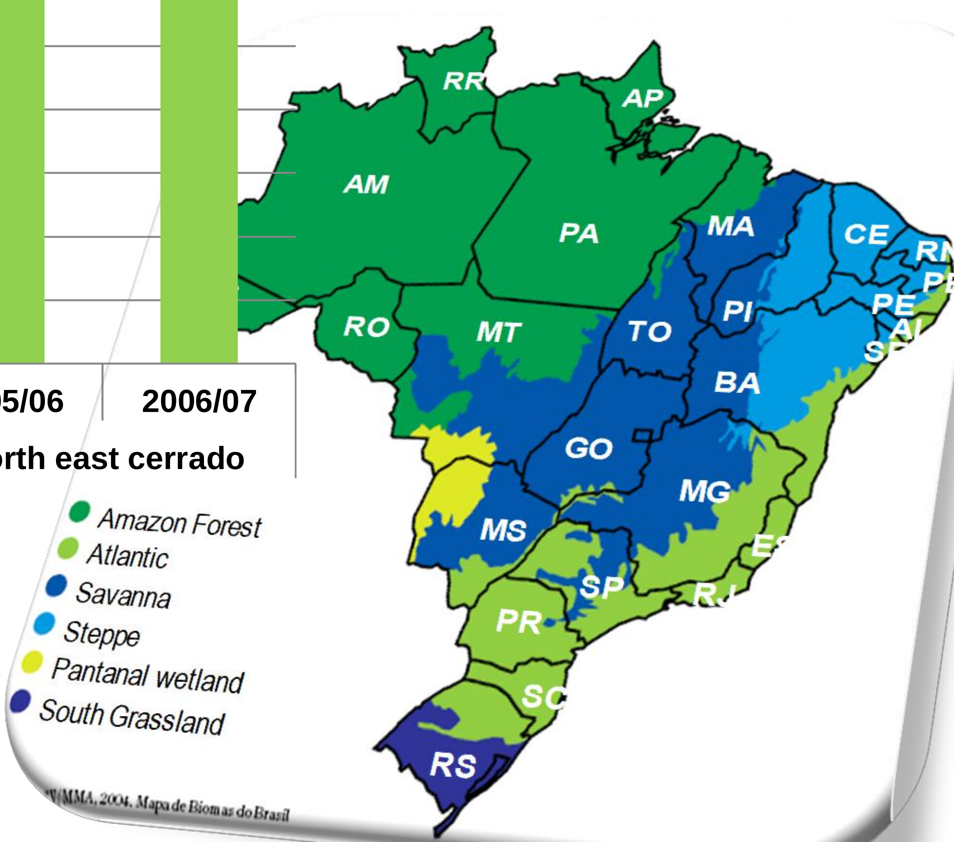
Polygons with deforestation characterized with agriculture or pasture (hectares, 2006/07)

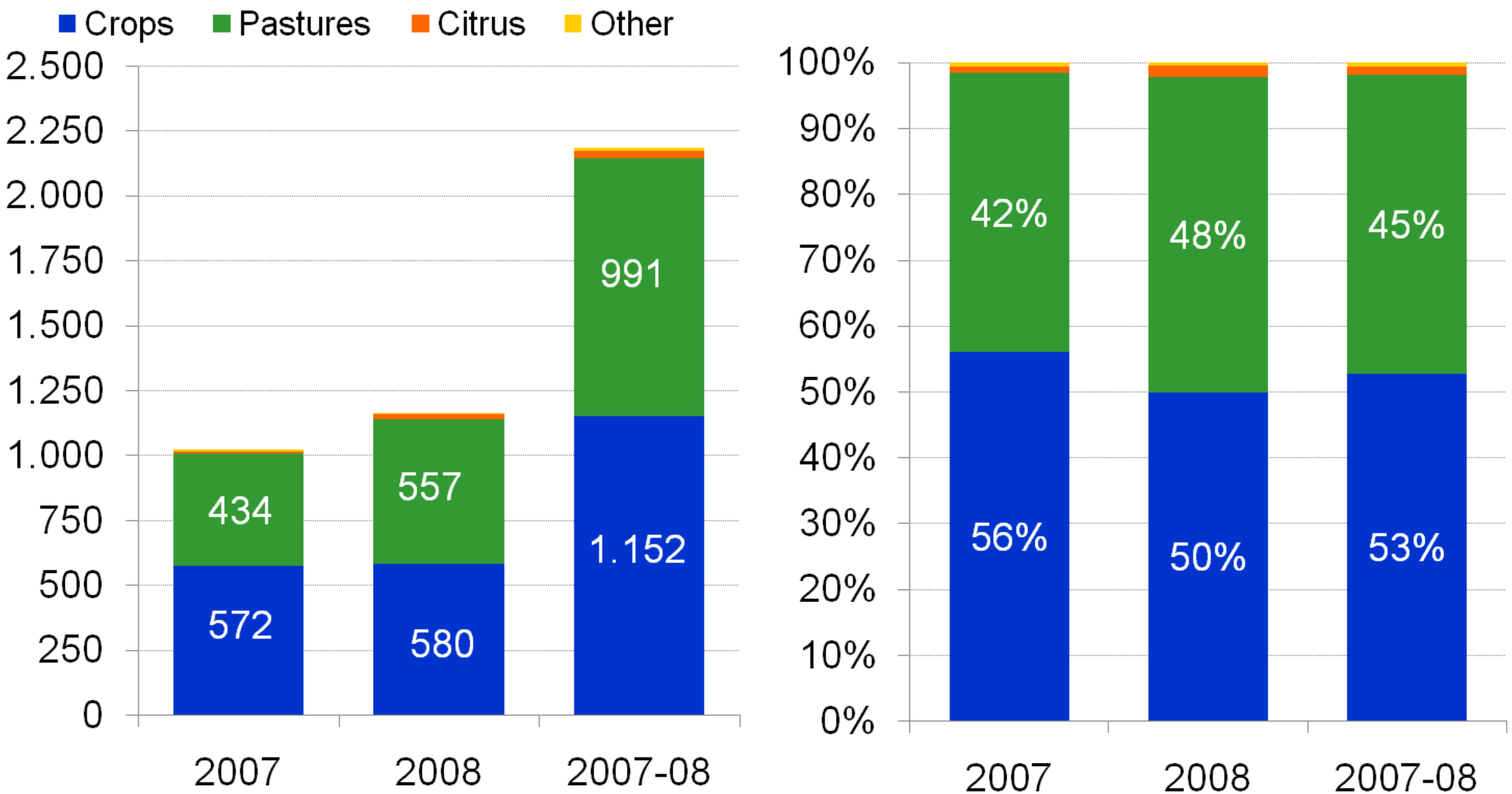




Source: ICONE and LAPIG – Laboratório de Processamento de Imagens e Geoprocessamento

Sugarcane expansion

South-Central Region: Classes of Land Use Converted to Sugarcane, 2007 and 2008
(1,000 ha)



Source: CANASAT/INPE, published in Nassar, A.M., Rudorff, B. F. T., Antoniazzi, L. B., Aguiar, D. A., Bacchi, M. R. P. and Adami, M, 2008. Prospects of the Sugarcane Expansion in Brazil: Impacts on Direct and Indirect Land Use Changes. In: Sugarcane Ethanol: Contributions to Climate Change Mitigation and the Environment. Zuurbier, P, Vooren, J (eds). Wageningen: Wageningen Academic Publishers.

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Weighted Average Profitability

- Weighted average profitability used for calculating scale and land supply elasticities;
- GIS evidences: LAPIG results for the Cerrados, Soybean Moratorium for the Amazon;
- Secondary results: Nassar et al. (2010), land allocation methodology

Regions	Activities	% Deforestation	Crops	% Crops	Regions	Activities	% Deforestation	Crops	% Crops
South	Crops	44	Corn	54	**Southeast**	Crops	39	Corn	20
			Soybean	30				Soybean	74
			Cotton	0				Cotton	0
			Rice	3				Rice	1
			Dry Bean	13				Dry Bean	5
	Sugarcane	1				Sugarcane	2		
	Pasture	55				Pasture	59		
Center West Cerrado	Crops	42	Corn	53	**North Amazon**	Crops	7	Corn	29
			Soybean	45				Soybean	69
			Cotton	0				Cotton	0
			Rice	1				Rice	0
			Dry Bean	2				Dry Bean	2
	Sugarcane	3				Sugarcane	0		
	Pasture	56				Pasture	93		
Northeast Cost	Crops	20	Corn	49	**Northeast Cerrado**	Crops	64	Corn	20
			Soybean	0				Soybean	34
			Cotton	3				Cotton	33
			Rice	3				Rice	3
			Dry Bean	46				Dry Bean	10
	Sugarcane	7				Sugarcane	0		
	Pasture	73				Pasture	36		

Source: calculated by the authors

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Land-use elasticities

- Land Supply Elasticities: ε^{Al}_{rl}

Regions	Previous Version	Updated Version
South	0.057	0.002
Southeast	0.067	0.007
Center West Cerrado	0.180	0.031
Northern Amazon	0.250	0.103
Northeast Coast	0.010	0.056
Northeast Cerrado	0.100	0.066

Source: calculated by the authors

- Own Elasticities not changed, based on literature.
- Scale and Competition elasticities recalculated based on new land supply elasticities and on competition ranking.
- New elasticities matrices for each one of the six regions in BLUM: very different from previous version.

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Sugarcane technology

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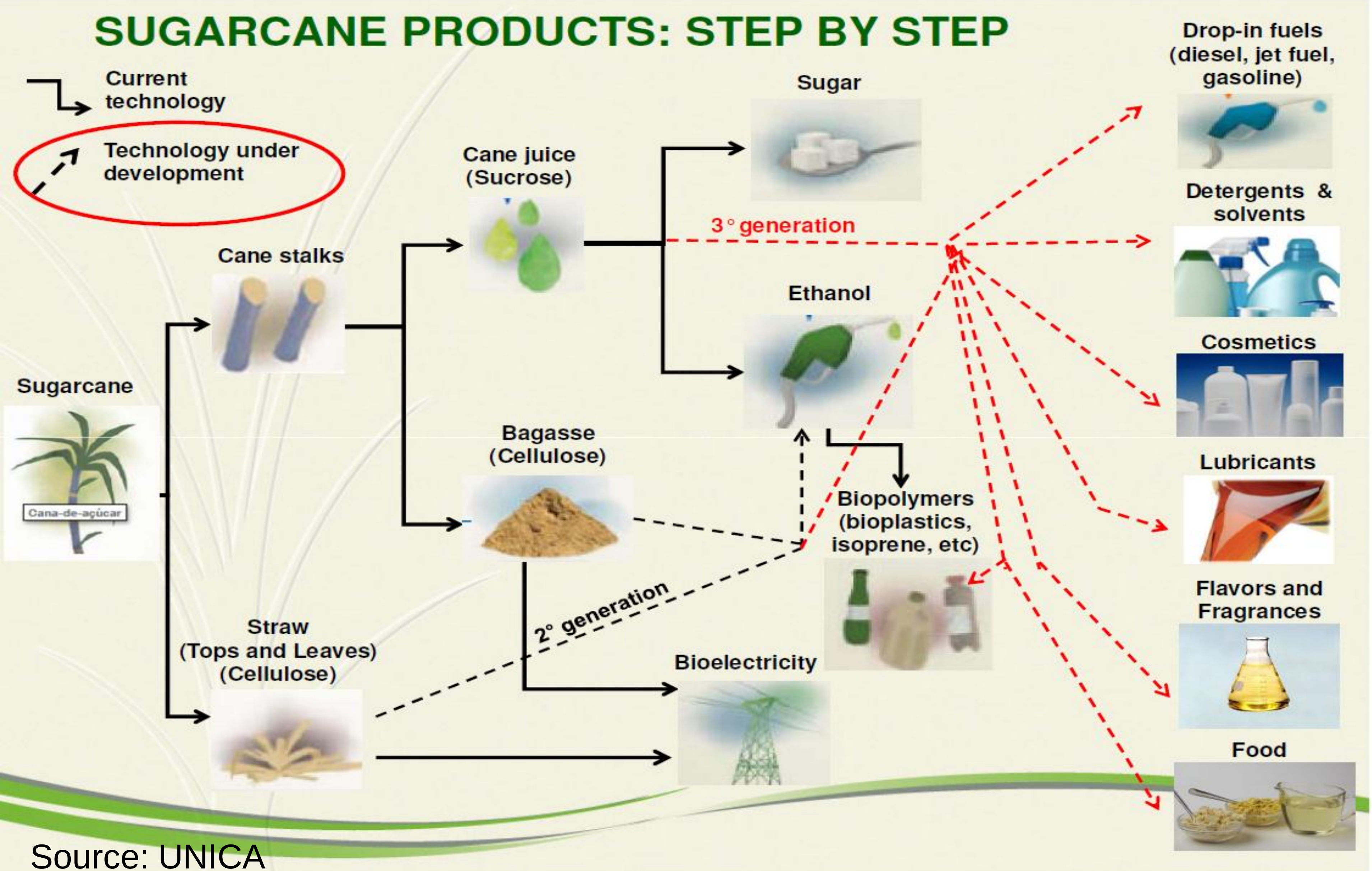
Industrial Technologies

Yields and base investment for different mill configurations

Industry type / yield per t of sugarcane	Ethanol (l/t of cane)	Sugar (kg/t of cane)	Electricity (kWh/cane)	Industrial Investment R$ mi*
Sugar only	0	102	0	322
Mixed	52	51	0	318
Autonomous	83	0	0	300
Mixed and low elec surpl	83	0	20	388
Mixed and high elec surpl	46	61	70	388
Ethanol, sugar and elec surpl(90bar)	46	61	76	392
Autonumous, elec, 90 bar, trash	83	0	162	460
Autonumous(2G), elec, 90 bar, trash	104	0	66	650

Note: Economies of scale are considerable. Costs of grid connection are considered for mills that sell electricity to the grid.
Source: CTBE and Dedini (2011), adapted by the authors.

Sugarcane products



Source: UNICA

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Changes in the sugarcane module

Original version

- **One Representative mill**
  - Only produces sugar and ethanol
  - Same final products in all regions

- **One national sugarcane price**

Sugarcane_tech version

- **Dynamic industrial profile**, considering:
  - Size of mills
  - Different final products
  - Different investments and industrial yields
  - Export of electricity

- **Local profitability, based on prices and local structure**

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Tecnology pannel

Industrial	Invest (R$/t)	Ethanol (l/t)	Sugar (kg/t)	KWh/t cane	Ethanol 2 G	Base	Tech
Sugar only [0, 1.5 M t], no electricity	211	-	102			OFF	OFF
Autonomous, [0, 1.5 M t], no electricity	197	83 (A)	-	-	-	OFF	OFF
Autonomous, [1.5, 3 M t], no electricity	174	83 (A)	-	-	-	4%	OFF
Mixed, [0, 1.5 M t], no electricity	221	26 (A) 27 (H)	51	-	-	7%	OFF
Mixed, [1,5, 3 M t], no electricity	195	26 (A) 27 (H)	51	-	-	4%	OFF
Mixed, [3, ∞ M t], no electricity	182	26 (A) 27 (H)	51	-	-	14%	OFF
Mixed, [0, 1.5 M t], low electricity	253	14 (A) 33 (H)	61	20	-	15%	OFF
Mixed, [1,5, 3 M t], low electricity	223	14 (A) 33 (H)	61	20	-	6%	OFF
Mixed, [3, ∞ M t], low electricity	208	14 (A) 33 (H)	61	20	-	2%	OFF
Mixed, [0, 1.5 M t], Hi electricity	255	14 (A) 33 (H)	61	70	-	15%	OFF
Mixed, [1,5, 3 M t], Hi electricity	225	14 (A) 33 (H)	61	70	-	26%	OFF
Mixed, [3, ∞ M t], Hi electricity	210	14 (A) 33 (H)	61	70	-	1%	OFF
Mixed, electricity Hi Hi sales, [3, ∞ M t]	212	14 (A) 33 (H)	61	76	-	4%	OFF
Autonomous, [1.5, 3 M t],elec, trash	252	83 (A)	-	162	-	7%	OFF
Autonomous, [3, ∞ M t],elec, trash	235	83 (A)	-	162	-	OFF	100%
Autonomous,[1.5, 3 M t],elec, cellulosic	325	104 (A)	-	66	20	OFF	OFF
Autonomous, [3, ∞ M t],elec, cellulosic	303	104 (A)	-	66	20	OFF	OFF
						OFF	OFF
						OFF	OFF

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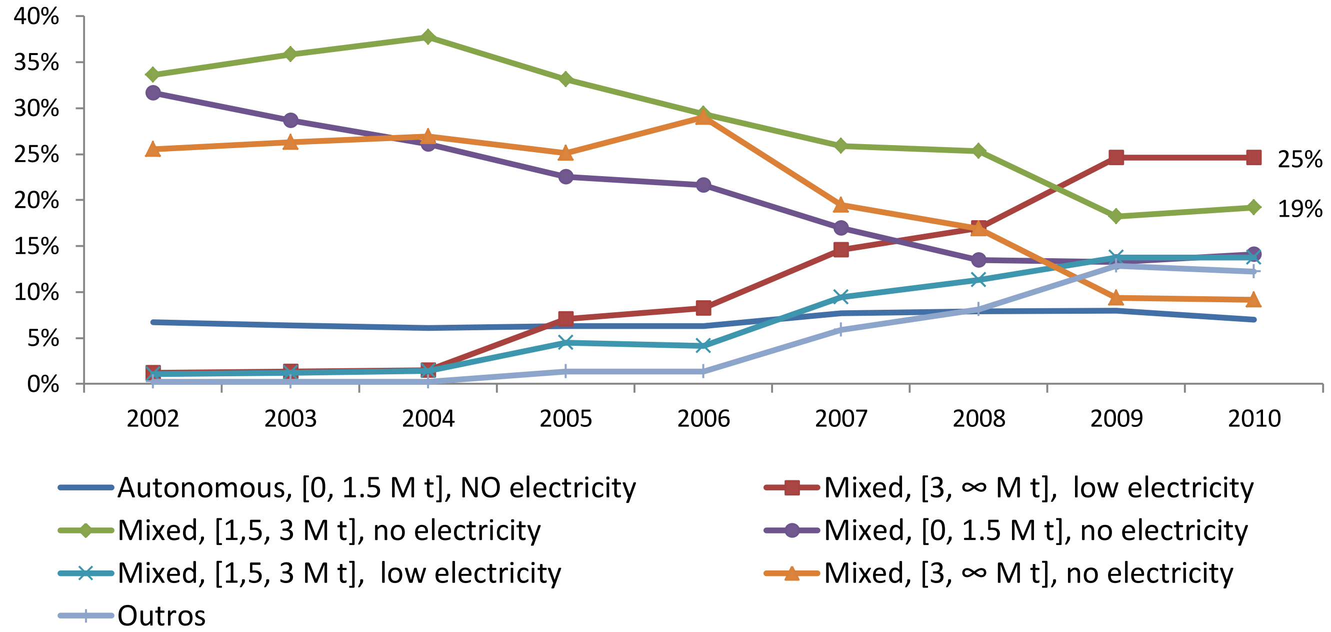
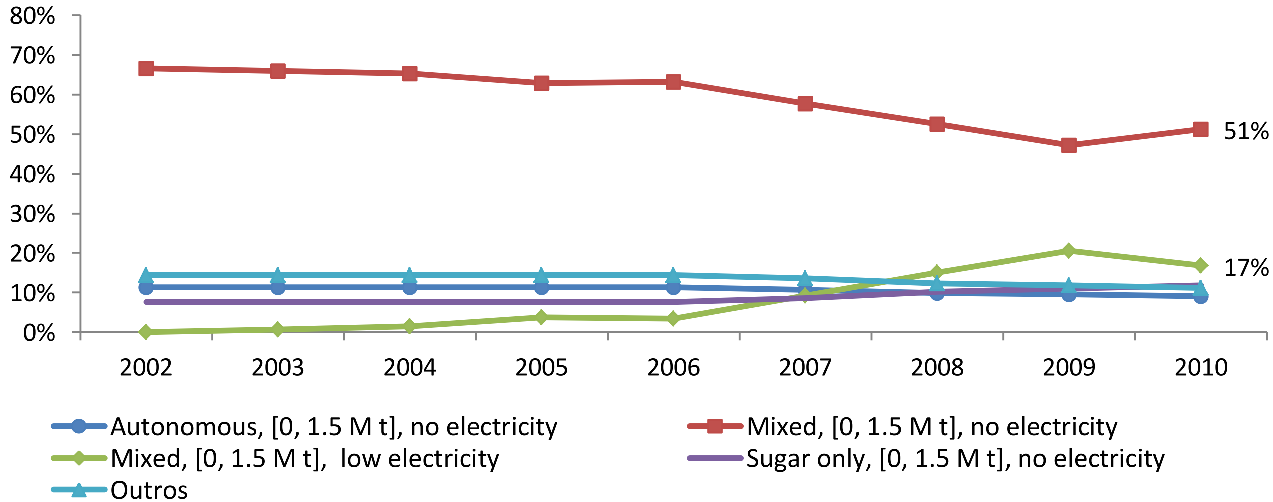
Regional industry profile: South-east

South-east



North-East litoral



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Simulation exercise: high efficient cogeneration boilers

Simulation exercise: assumptions

End date: 2022

Scenarios:

Technology:

Baseline:

- Share of industry profile kept constant (based in 2010)
- Electricity price: 100 MWh (last public auction)

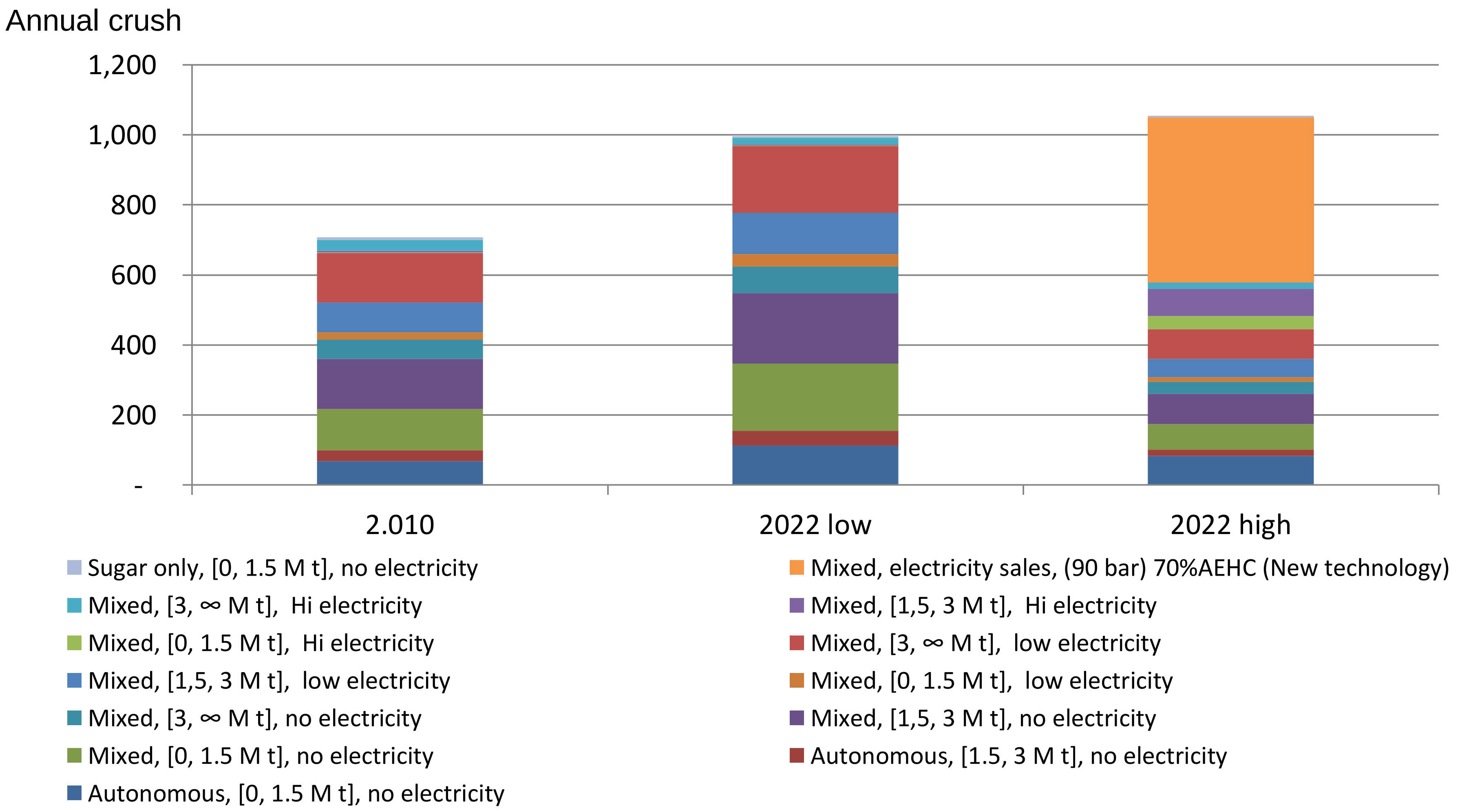
Highly efficient cogeneration:

- Only best technologies of each region (optimized)
- High electricity performance (MWh/ t cane)
- Highest size for each region
- New technology on additional crush and depletion of old mills
- Electricity price: 200 MWh

Demand:

- Exactly the same demand structure in both scenarios (equations and parameters)

Technology profile



Strong sugarcane expansion allows for intense adoption of high-eficient technology.

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Supply and demand balance

Product	Variable	2010	Low Tech	Hi Tech	% variation
Sugarcane	Total cane	734	998	1.016	1,80%
	Crush for mills	623	895	911	1,79%
Sugar	Price (R$/t)	801	1.111	1.040	**-6,42%**
	Production (t)	38233	**48.493**	**48.915**	0,87%
	Per-Capita Consumption (kg)	53	61	61	0,79%
	Domestic Consumption (t)	10700	13806	13915	0,79%
	Ending Stocks(t)	1087	1554	1617	4,10%
	Net Trade(t)	27946	34660	34973	0,90%
Ethanol	Price	1,05	1,95	1,84	**-5,82%**
	Production	27576	**49165**	**50353**	2,41%
	Hydrous consumption	16142	32495	33707	**3,73%**
	Anhydrous consumption	8113	14447	14253	-1,34%
	Industrial consumption	1600	1000	1000	0,00%
	Domestic total consumption	25855	47942	48959	2,12%
	Ending Stocks	2760	3024	3103	2,61%
	Net Exports	1725	1205	1372	13,84%
Eletricity	Surplus (TWh)	7.57	8.42	47.68	39,2

Indirect effects: sugar has higher **price** reduction and ethanol has higher expansion on (hydrous) **production**.

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Land Use (sugarcane area)

Sugarcane area (1000 ha)

Region	2010	2022 Low Tech	2022 High Tech	Absolute variation
South	680	876	910	34
Southeast	6152	7186	7333	147
Center-west cerrado	1196	1432	1452	20
North Amazon	143	203	174	-29
Northeast Coast	1084	1447	1466	19
Northeast/ Cerrado	160	259	263	4
Brazil	9416	11402	11596	194

Indirect effects: higher expansion in traditional regions reduces profitability (and area) in the Amazon.

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Land Use (Ag-land)

Agricultural and pasture (1000 ha)

Region	2010	Low Tech, low price	Hi Tech, Hi price	Variation
South	29.112	29.178	29.178	0
South-east	37.242	37.033	37.034	1
Center West Cerrado	58.464	59.800	59.802	2
North Amazon	51.525	54.767	54.779	13
Northeast Coast	14.116	14.907	14.912	5
Northeast/ Cerrado	35.817	36.655	36.657	1
Brazil	226.276	232.341	232.362	21

Indirect effects: High capacity for other sectors to absorb marginal sugarcane expansion. North Amazon still have highest response to pasture return.

LUC emissions according to EPA method used in RFS2

Total 30 years emissions (1000 t)	Annual 2 Perrenial	Pasture 2 Perrenial	Pasture 2 Annual	Natural 2 Annual	Natrual 2 Perrenial	Natural 2 Pasture	Total region
South	(1.548)	308	-	-	6	-	(1.235)
Southeast	-	2.383	562	98	-	-	3.042
Central-West Cerrados	-	272	111	382	-	-	765
Amazon Biome	220	-	-	215	-	3.307	3.742
Northeast Coast	(476)	145	-	-	181	-	(150)
North-Northeast Cerrados	-	51	-	15	57	-	123
Total Emissions	(1.804)	3.159	673	710	243	3.307	6.287

Annualized LUC emissions = 210 thousand tons CO_2e
Much smaller then avoided emissions 15.7 million t of CO_2e (39TWh from natural gas) !

Conclusions / Recommendations

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From GIS and economic links

“LUC Models that better replicate reality give better insights”

Facts:

Drivers of deforestation are hard to identify (deforestation ≠ Ag expansion)

Drivers of deforestation varies across regions.

Deforestation due to sugarcane expansion is virtually inexistent

Conclusions

Buffers or lower elasticities can be used to link agriculture and deforestation (possible solution)

Weights of Ag expansion functions should vary depending on the region.

Recommendations

Should keep improving databases and links between GIS and economics

Pasture and livestock sector needs most of the investments

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From technology package

"Technology can make a lot of difference!?"

Facts:

Ethanol technology is changing fast

Innovative technologies on the pipeline: new feedstock (trash), new conversion tech (2G), new products (biojet fuel, biochemicals)

Conclusions

Actual high cogen systems shows limited potential to boost sugarcane acreage

Some regional reallocation of sugarcane expansion is probable

Indirect effects are much smaller (21 from initial 194 ha)

LUC emissions much smaller than avoided emissions

Higher income and lower prices !

Recommendations

Need to analyze other technologies (industrial and agricultural)

Other possible/different analysis?

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Improving GIS database and models:

The BLUM model

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Contributions and Conclusions

Innovative methodology is propose to deal with technological pathways.

- Important database on industry profile generated for this project

Main findings

- ➢The large scale adoption of efficient cogeneration technology resulted in 39.2 additional TWh in 2022.
- ➢This amount of energy would release 15.7 million t of CO2e if natural gas (combined cycle) is the alternative for bioelectricity
- ➢The additional emissions from lUC and iLUC are somewhat insignificant (around 324 thousand t of CO2e)

Unexpected important findings

- ➢expand sugar and ethanol production and consumption, and at the same time to reduce sugar and ethanol prices.
- ➢Hydrous ethanol consumers would greatly benefit from the decline in

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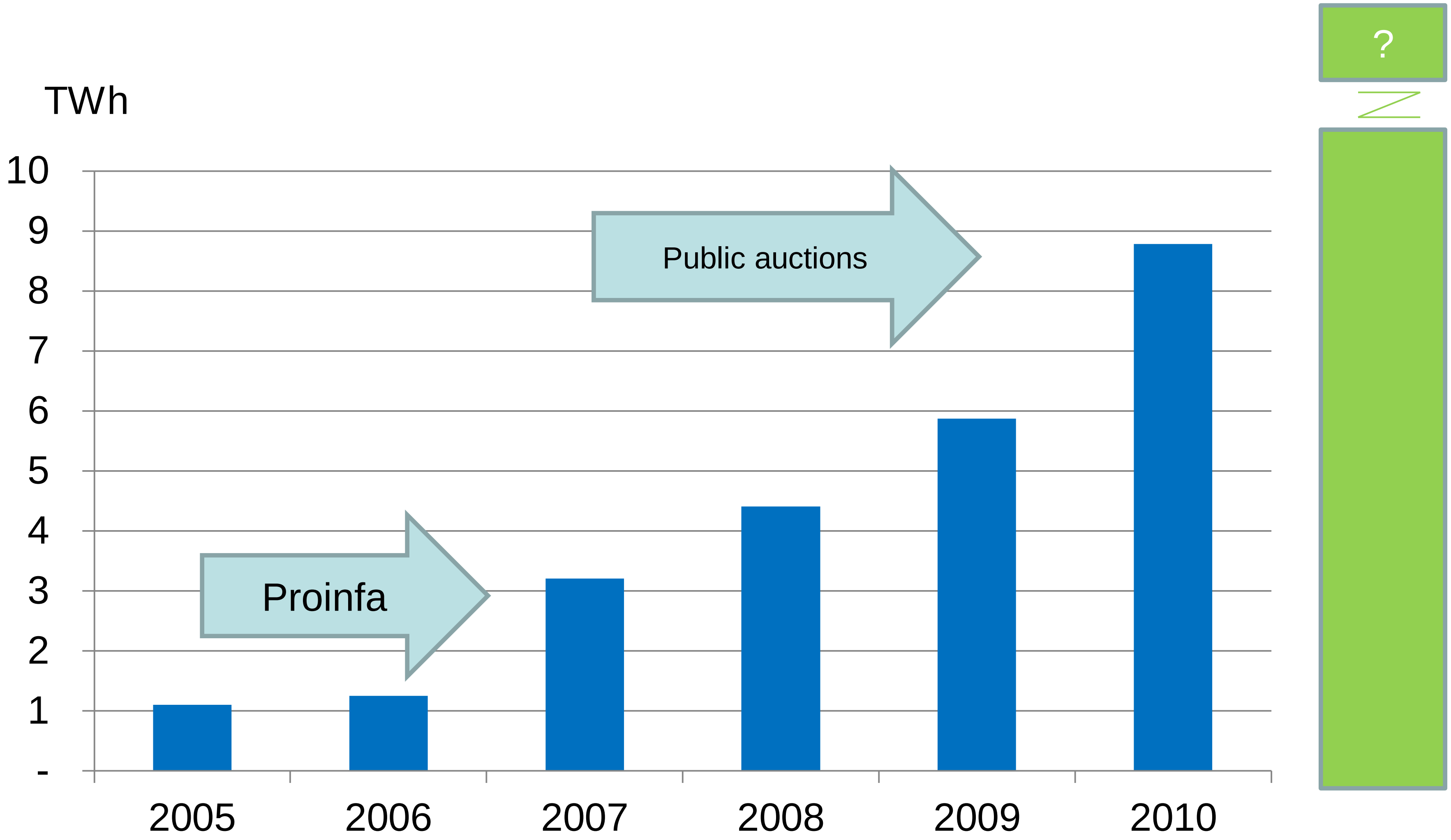
Recommendations and future work

Recommendations ad future work.

- Allocation methodologies related to technological innovations are not discussed in this paper and should be further investigated.
- we recommend a similar study be carried out keeping electricity prices constant across scenarios.
- Analysis of other technologies, such as the additional electricity generation from sugarcane trash and second generation biofuels.

Trends in electricity surplus from sugarcane mills



Source:UNICA and ministry of energy

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Brazil: Land Use

Land Use	Area (1,000 ha)	Total/Brazil
National parks and indigenous reserves	175,020	21%
Remaining vegetation	369,396	43%
Pastures	182,336	21%
Annual crops	49,204	6%
Perennial crops	6,496	1%
Commercial forests	6,126	1%
Cities and water	35,352	4%
Other uses	27,558	3%
Total	851,488	100%

Fonte: Agricultural Land Use and Expansion Model – Brazil - AgLUE-BR (Gerd Sparovek, ESALQ-USP), IBGE, ABRAF.
Elaboração: ICONE

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Profile of the sugarcane industry: key findings

- **Tendency for product diversification**
  - All mills higher then 3 MMt /year produces sugar and ethanol
  - Very few mills produces sugar only (only small mills in the North-east region)
  - 60% of electricity sold in mills with annual crush over 3 MMt year.
  - More than 70% of the mills higher then 3 MMT sells electricity
  - Risk aversion; technological restrictions
- **Huge expansion of electricity sales in recent years**; especially on the new mills and CS region
- **CS Industry profiles are much more diversified**
- **Ethanol only mills concentrated on the Center West region**
  - mills are still smaller than expected on Center West.
- **Sugar only mills restricted to the North-east Litoral region.**
- **Electricity efficiency (MWh/ t of cane) much better in CS regions.**

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Pasture intensification

Variable	Unit	1996	2008	Growth rate	Total Variation in the Period
Beef Production	Million Tons	6,186.9	9,765.4	5.34%	57.8%
Pasture Area	Million Hectares	184,141	180,143	-0.14%	-2.17%
Slaughter Rate	% of Cattle Herd	0.1781	0.2175	2.57%	22.1%
Stock Rate	Heads/Hectare	0.8596	1.1111	2.69%	29.3%
Carcass Weight	Tons/Head	0.2194	0.2243	0.16%	2.24%
Beef per Hectare	Tons/Hectare	0.0336	0.0542	5.49%	61.3%

Source: ICONE, original data from IBGE, UFMG and ICONE

Huge stock of pasture area, and significant rate of pasture intensification. But production has also grown very fast.

Technologies

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Original version

- **One Representative mill**
  - Only produces sugar and ethanol
  - Same final products
- **One national sugarcane price** transmitted to the six regions
- **Sugarcane price sensible to TRS (national)** content.
- **Constant industrial processing costs**
- **Regional agricultural costs**

$$\pi_{cane} = (p_{cane} * y_{cane}) - CT_{cane}, \textit{and}$$

$$CT_{cane} = Cag + Cind$$

Sugarcane_tech version

- **Dynamic industrial profile**, considering:
  - Size of mills
  - Different final products
  - Different investments and industrial yields
  - Export of electricity
- **Regional prices for sugar, ethanol and electricity**
- **Production sensible to TRS (regional)**

$$\pi_{cane} = \sum_{i=1}^{n} \pi_{cane,i} * s_i, \text{ where}$$

s_i is the share of tech i, and

$$\pi_{cane,i} = \pi_{ton\_cane,i} * y, \text{and}$$

$$\pi_{ton\_cane,i} = \frac{EAV_{mill\ i}}{crush_{mill\ i}}$$

*

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4 methodological steps

- **1. First Stage:** identification and mapping mills current technologies (existing and innovative) and representing them as "*standard mills*" (S/E/EI; Size (crush); MWh/tsc)
- **2. Second Stage:** establishment of the profile of the sugarcane industry across time/regions, according to the existing technology (by collecting industry data). Once the technological profile is created, it will be represented in the BLUM through a combination of the standard mills of "first stage".
- **3. Third Stage:** simulation of the sugarcane expansion in the BLUM according to the predefined technological scenarios (technologies control panel).
- **4. Fourth Stage:** analysis of the technology impact (cogeneration). In order to measure the environmental impacts of the cogeneration technology, one scenario serves as a *baseline* (using conventional technology) and the others consider *highly efficient cogeneration systems (90 bar boiler – CTBE).* Equilibriums are compared.

BLUM Formal Description (land use section)

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- The area of each i activity in region l and time t (a_{ilt}) is defined as

$$a_{ilt} = A^T m(r_{lt}) s_{ilt}(r_{ilt}, r_{-ilt})$$

A^t is the total land available in the region (estimated from GIS);
m is the share of land in agricultural uses in region
$S_{ilt}(r_{ilt}, r_{-ilt})$ is the share of the agricultural land devoted to activity i, region l and time t.

- The share of total area that is dedicated to agricultural production follows a function such as:

$$m_{lt} = \frac{A_{lt}}{A_l^T} = kr_{lt}^{\varepsilon_{\eta}^{A_l}} \quad \Rightarrow \quad m_{lt} = \frac{A_{lt}}{A_l^T} = kr_{lt}^{\alpha_{lt}\varepsilon_{\eta}^{A_l}}$$

Where: $$\alpha_{lt} = 1 - \frac{A_{lt} - A_{l0}}{A_l^T}$$

k is a parameter to be defined, r_t is the average revenue of the region, ε is the land supply elasticity. The parameter α_{lt} is positive, higher or lower than one and is defined in each t.

- For the country $$A_{it} = \sum_{l=1}^{6} a_{ilt}$$

- Product elasticities:

Scale | Competition

Cross elasticities
$$\varepsilon_{r_{lj}}^{l,i} = \frac{\partial m_l(r_{lt})}{\partial r_{lt}} \frac{\partial r_{lt}}{\partial r_{jlt}} \frac{r_{jlt}}{m_l(r_{lt})} + \frac{\partial s_{ilt}(r_{ilt}, r_{-ilt})}{\partial r_{jlt}} \frac{r_{jlt}}{s_{ilt}(r_{ilt}, r_{-ilt})}$$

Own elasticities
$$\varepsilon_{r_{li}}^{l,i} = \frac{\partial m_l(r_{lt})}{\partial r_{lt}} \frac{\partial r_{lt}}{\partial r_{ilt}} \frac{r_{ilt}}{m_l(r_{lt})} + \frac{\partial s_{ilt}(r_{ilt}, r_{-ilt})}{\partial r_{ilt}} \frac{r_{ilt}}{s_{ilt}(r_{ilt}, r_{-ilt})}$$

*

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Land Use GHG emissions

Land Use GHG emissions from baseline to high-tech scenario

Region	30 years emissions (t CO2/ha)	LUC (1000 ha)	Total 30 year emission (t CO2/ha)	Annual emissions (t CO2/ year)
South	235	0,11	25106	837
South-east	253	0,64	160977	5.366
Center-west cerrado	300	2,04	611088	20.370
North Amazon	616	12,66	7794769	259.826
Northeast Coast	155	4,58	709784	23.659
Northeast Cerrado	330	1,23	406087	13.536
Total	NA	21,25	9.707.811	323.594

Source: emission data from EPA (2010), calculated by the authors.

Simplified calculations. Considers direct emission balance between of natural vegetation and sugarcane

Obtaining consistent land use elasticities

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Own return elasticities

Homogeneity
$$\sum_j s_{ij} = 0$$

Symmetry
$$s_{ij} = s_{ji}$$

Adding up
$$\sum_i s_{ij} = 0$$

Aditional information:
- Agronomic similarity (GIS)
- level of competition due to investments
- others

Scale elasticities

Competition elasticities (1st crops) *

	Corn1	Soyb.	Cotton	Rice	beans	Scane	Past.
Corn 1st crop	0,18	-0,26	0,00	0,00	0,00	-0,03	0,00
Soybeans	-0,07	0,40	0,00	0,00	0,00	-0,01	-0,02
Cotton	-0,05	-0,07	0,21	-0,03	0,00	-0,06	0,00
Rice	0,00	-0,02	0,00	0,15	-0,03	0,00	0,00
Dry beans 1	-0,03	-0,01	0,00	-0,22	0,09	-0,01	0,00
Sugarcane	-0,04	-0,04	0,00	0,00	0,00	0,39	0,00
Pasture	0,00	-0,13	0,00	0,00	0,00	0,00	0,01

area

Total ag-land elasticity

Returns

External
Estimated
Calculated

(*) Note: elasticities values are preliminary

*

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Technologies

Original version

- **One Representative mill**
  - Only produces sugar and ethanol
  - Same final products
- **One national sugarcane price** transmitted to the six regions
- **Sugarcane price sensible to TRS** content.
- **Constant industrial processing costs**
- **Regional agricultural costs**

Sugarcane_tech version

- **Dynamic industrial profile**, considering:
  - Size of mills
  - Different final products
  - Different investments and industrial yields
  - Export of electricity
- **Regional prices for sugar, ethanol and electricity**
- **Product yields sensible to TRS**

Simplified representation of sugarcane regional return

Original version

$$\pi_{cane} = (p_{cane} * y_{cane}) - CT_{cane}, \textit{ and}$$

$$CT_{cane} = Cag + Cind$$

Sugarcane_tech version

$$\pi_{cane} = \sum_{i=1}^{n} \pi_{cane,i} * s_i, \text{ where}$$

s_i is the share of tech i, and

$$\pi_{cane,i} = \pi_{ton\_cane\,i} * y, \text{and}$$

$$\pi_{ton\_cane\,i} = \frac{EAV_{mill\,i}}{crush_{mill\,i}}$$

*

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Robust database

1. Regional agricultural characteristics of sugarcane production;

Yield (TRS/t cane); Yield (t/ha); Ag Operational cost (R$/ha); Ag Operational cost (R$/ t cane)

2. Yields and base investment for different mill configurations;

Industry type / yield per t of sugarcane; Ethanol (l/t of cane); Sugar (kg/t of cane); Electricity (kWh/cane); Industrial Investment R$ mi

3. Regional industry profile in 2010, according to final products and annual crush

Annual crush MMT (0 to 1.5; 1.5 to 3; 3to∞); sugar and ethanol; ethanol only …

4. Main regional characteristics of electricity sales by sugarcane mills

Total cane in mills that sell electricity, Energy sold, Kwh/t of cane

5. Sugarcane crushed in mills that export electricity

Total and share by mill size

6. Total electricity exported by the mills on the regulated market

Time series of traded electricity (MWh; Mwme)

7. Characteristics of the mills that won public auctions

(mills that reached total electricity sold in the auctions in 2010 and mills that did not reach total electricity sold in the auctions in 2010)

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Table1: Regional agricultural characteristics of sugarcane production,

Region	yield (TRS/t cane)	Yield (t/ha)	Operational Cost (R$/ha)	Operational Cost (R$/ t canse)	Share of national production
South	137	74	2737	37	8%
South-east	142	83	2994	36	71%
Center West cerrado	142	81	3071	38	8%
North Amazon	126	66	2552	39	1%
Northeast Coast	132	55	2486	45	10%
Northeast cerrado	130	64	2975	46	2%
Brazilian average	141	78	2924	38	100%

Note: Operational costs include field costs and transportation of sugarcane to the mill. Land rent and opportunity cost of capital are not considered.

Source: Original data from MAPA, IBGE, PECEGE/ESALQ, Agra FNP, elaborated for this study.

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Table 2: yields and base investment for different mill configurations

Industry type / yield per t of sugarcane	Ethanol (l/t of cane)	Sugar (kg/t of cane)	Electricity (kWh/cane)	Industrial Investment R$ mi
Ethanol only	83	0	0	300
Sugar only	0	102	0	322
Ethanol and sugar	52	51	0	318
Ethanol sugar and low electricity	83	0	20	388
Ethanol, sugar and high electricity	46	61	70	388
Ethanol, sugar and electricity 90bar	46	61	76	392

Note: Costs of grid connection are considered for mills that sell electricity to the grid.
Source: CTBE and Dedini (2011), adapted by the authors.

Economies of scale are considerable. Literature review indicates that it is fair to consider a 10% economy per ton of cane for mills above 3 MT per year; base investment for mills below 1.5 MT/year suffer an increase of 13% per t of cane (OLIVÉRIO, 2007).

Table 3: Regional industry profile in 2010, according to final products and annual crush

Annual crush	Final products	South	South-east	Center West Cerrado	North Amazon	Northeast Coast	Northeast Cerrado	Brazil
<1,5	Ethanol	12%	7%	21%	16%	9%	53%	10%
1,5<..<3	Ethanol	0%	4%	13%	0%	0%	0%	5%
>3	Ethanol	0%	0%	0%	0%	0%	0%	0%
<1,5	Mixed	23%	14%	9%	84%	68%	47%	19%
1,5<..<3	Mixed	41%	33%	39%	0%	11%	0%	32%
>3	Mixed	23%	40%	19%	0%	0%	0%	31%
<1,5	Sugar	0%	2%	0%	0%	12%	0%	2%
1,5<..<3	Sugar	0%	0%	0%	0%	0%	0%	0%

Source: from the authors, using data from CONAB, MAPA and Procana.

*

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Table 4: main regional characteristics of electricity sales by sugarcane mills

Region	Total cane in mills that sell electricity	Energy sold	Kwh/t of cane
South	11.627.389	380.221	33
South-east	219.301.280	5.772.466	26
Center West Cerrado	28.246.466	792.756	28
North Amazon	0	0	na
Northeast Coast	21.477.398	341.534	16
Northeast Cerrado	1.866.233	17.550	9
Brazil	282.518.766	7.304.527	26

Source: original data from CONAB (2011), elaborated by the authors.

*

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Table 5: Sugarcane crushed in mills that export electricity (total and share by size)

	São Paulo		Center South		NE and north	
Class of crush Million t /year	Crush Million t	Share of the class*	Crush Million t	Share of the class*	Crush Million t	Share of the class*
[3 , ∞]	124.070	76%	34.296	84%	NA	NA
[1.5 ;3.0]	59.495	44%	20.746	30%	10.611	64%
[0,1.5]	9.387	15%	11.182	16%	13.211	30%

*Share of the class means the share of the mills within a size class that exports electricity.
Source: original data from CONAB (2011), elaborated for this study.

*

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Table 6: total electricity exported by the mills on the regulated market

Electricity Sells	2005	2006	2007	2008	2009	2010e
MW “average”	126	143	366	503	670	1,005
MWh	1,103,000	1,253,000	3,208,000	4,406,280	5,869,200	8,808,00 0
Evolution	-	14%	156%	37%	33%	57%

Note: 2010 values are estimated.

Source: MME, UNICA and from the authors.

*

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Table 7: Characteristics of the mills that won public auctions (mills that reached total electricity sold in the auctions in 2010)

	Crush (Million t)	Number of mills	% of crush
Total	55,57	20	100%
Bigger than 3 Mt	28,49	8	51%
Between 1,5 e 3 Mt	25,84	11	47%
Smaller than 1,5 Mt	1,23	1	2%
Mixed	51,33	18	92%
Ethanol only	4,24	2	8%
Kwh/t (average)	44,59	-	-

Source: MME, elaborated by the authors

*

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Table 8: Characteristics of the mills that won public auctions

(mills that did not reach total electricity sold in the auctions in 2010)

variable	Crush (Million t)	Number of mills	% of crush
Total	72,55	29	100%
Bigger than 3 Mt	35,69	7	49%
Between 1,5 e 3 Mt	27,54	12	38%
Smaller than 1,5	9,31	10	13%
N of Mixed	61,28	20	84%
N of autonomous	11,26	9	16%
Kwh/t (average)	36,63	-	-

Source: MME, elaborated by the authors.

*

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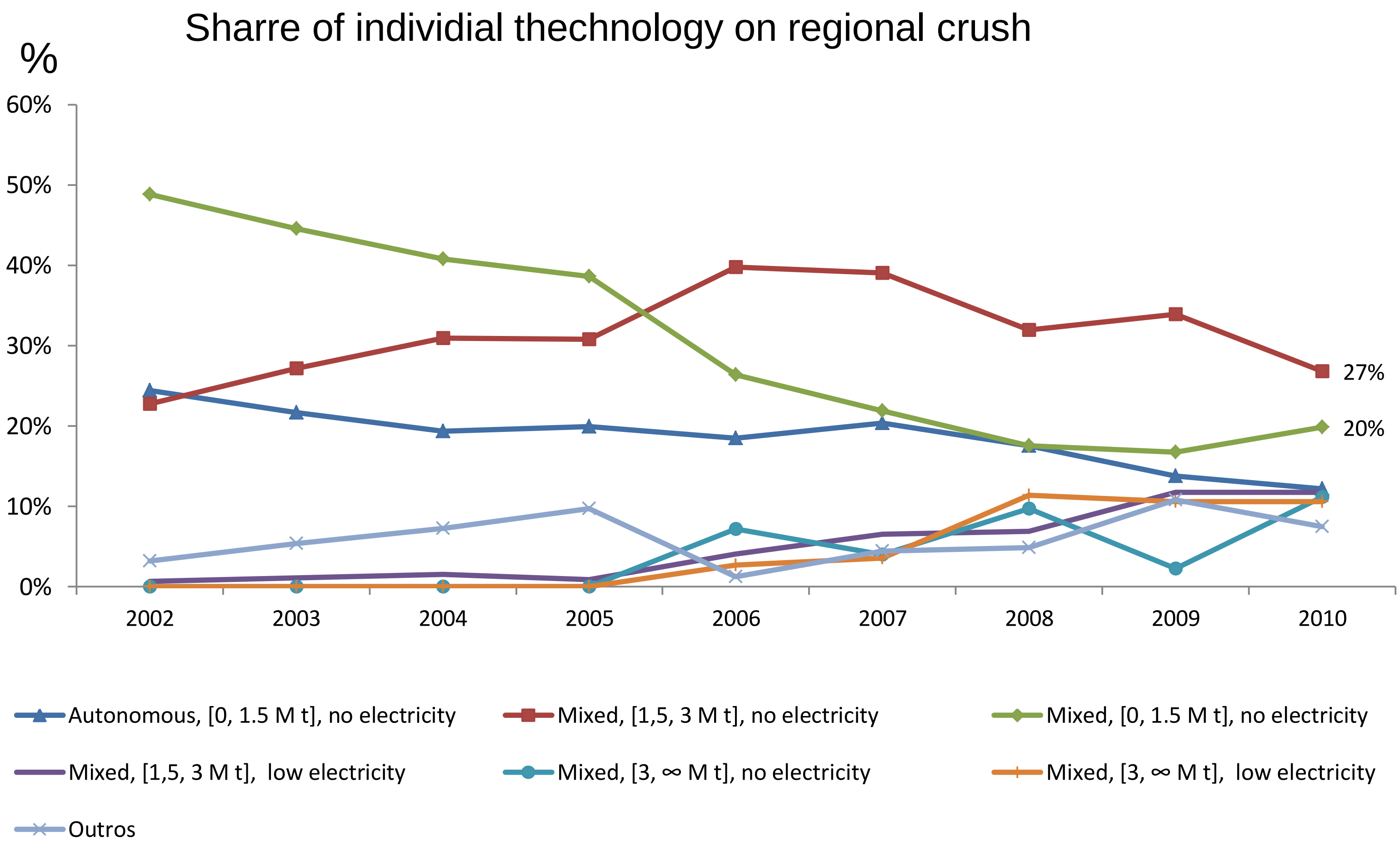
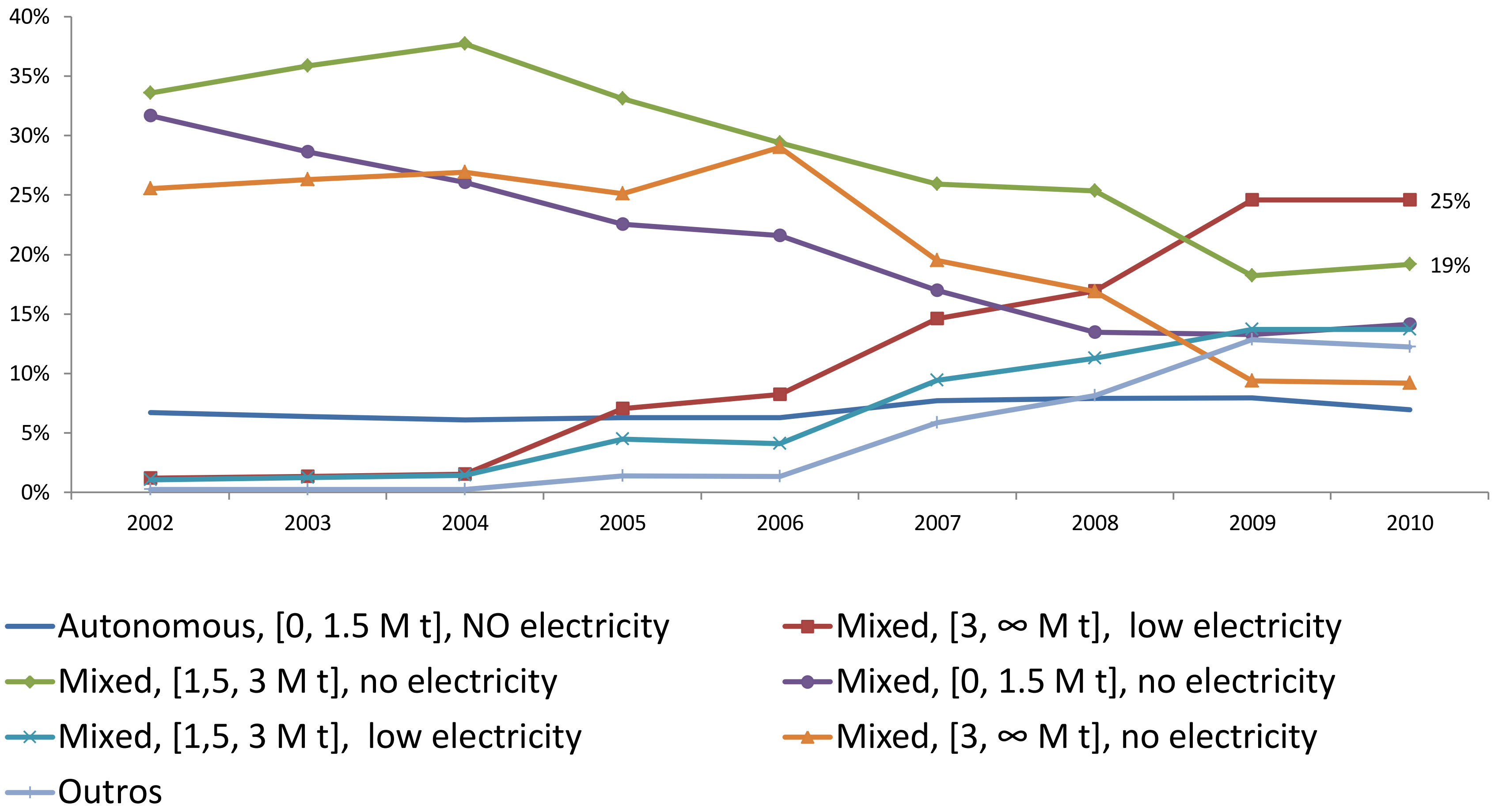
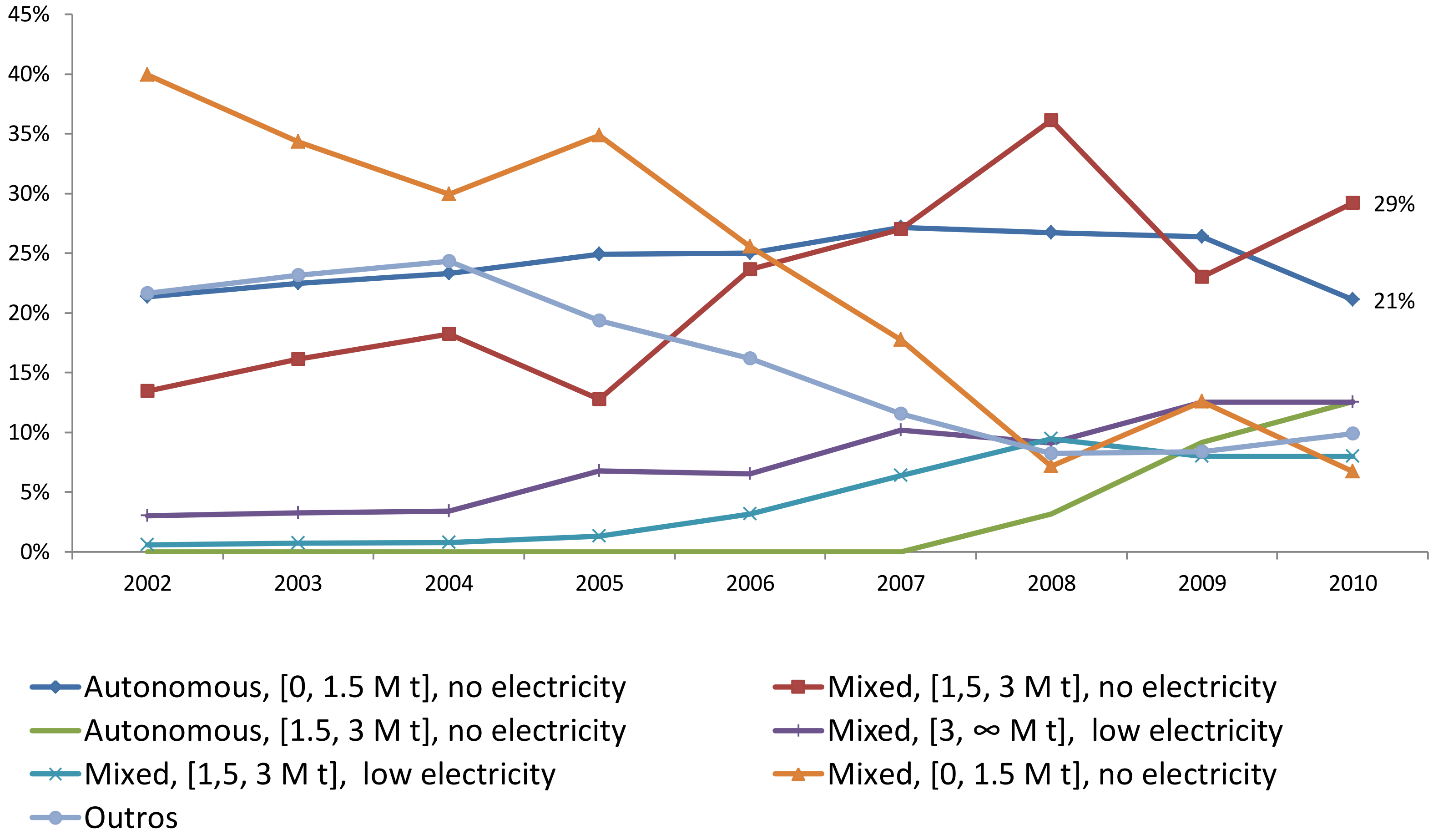
Regional industry profile: South



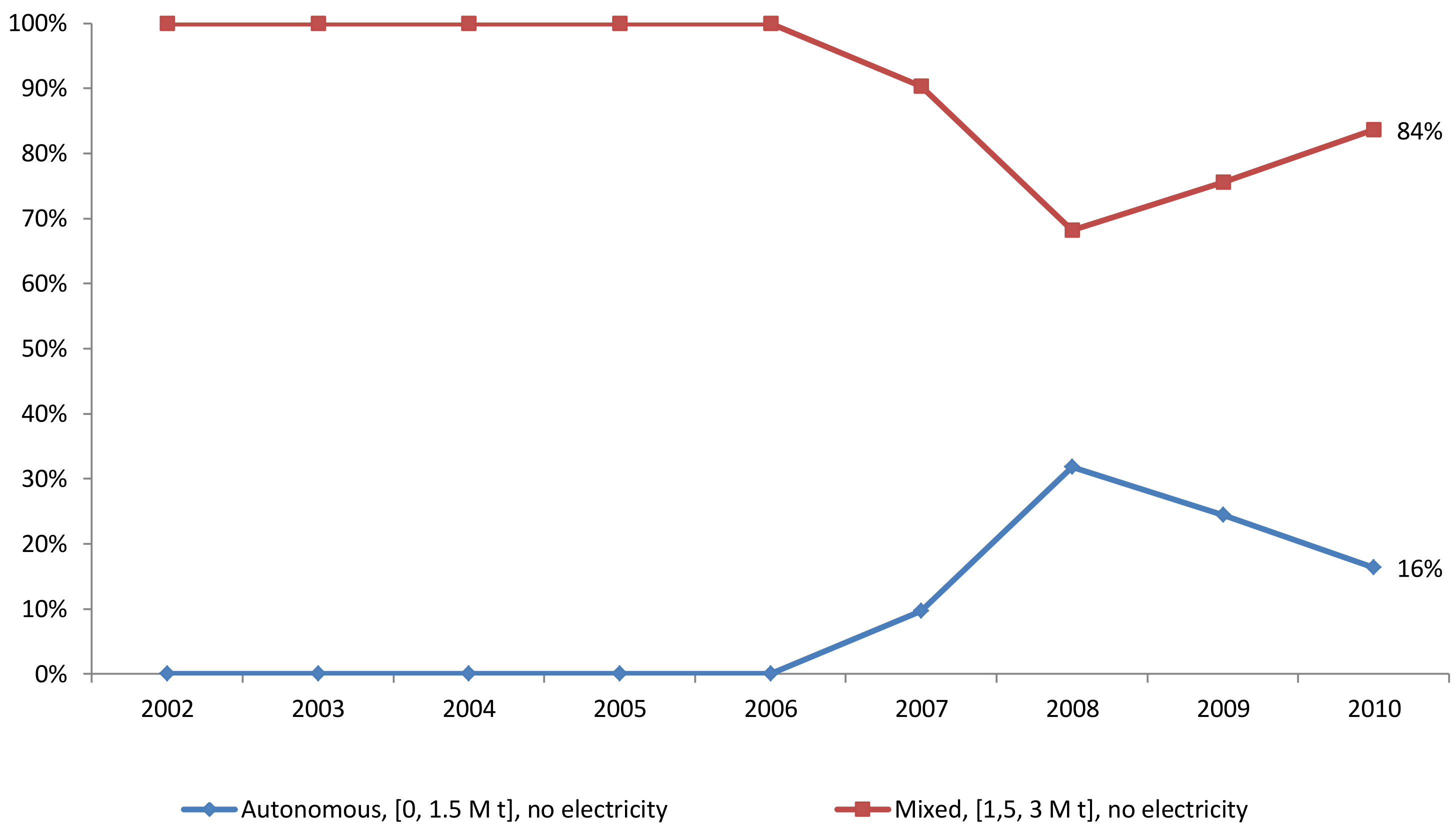
Regional industry profile: South-east



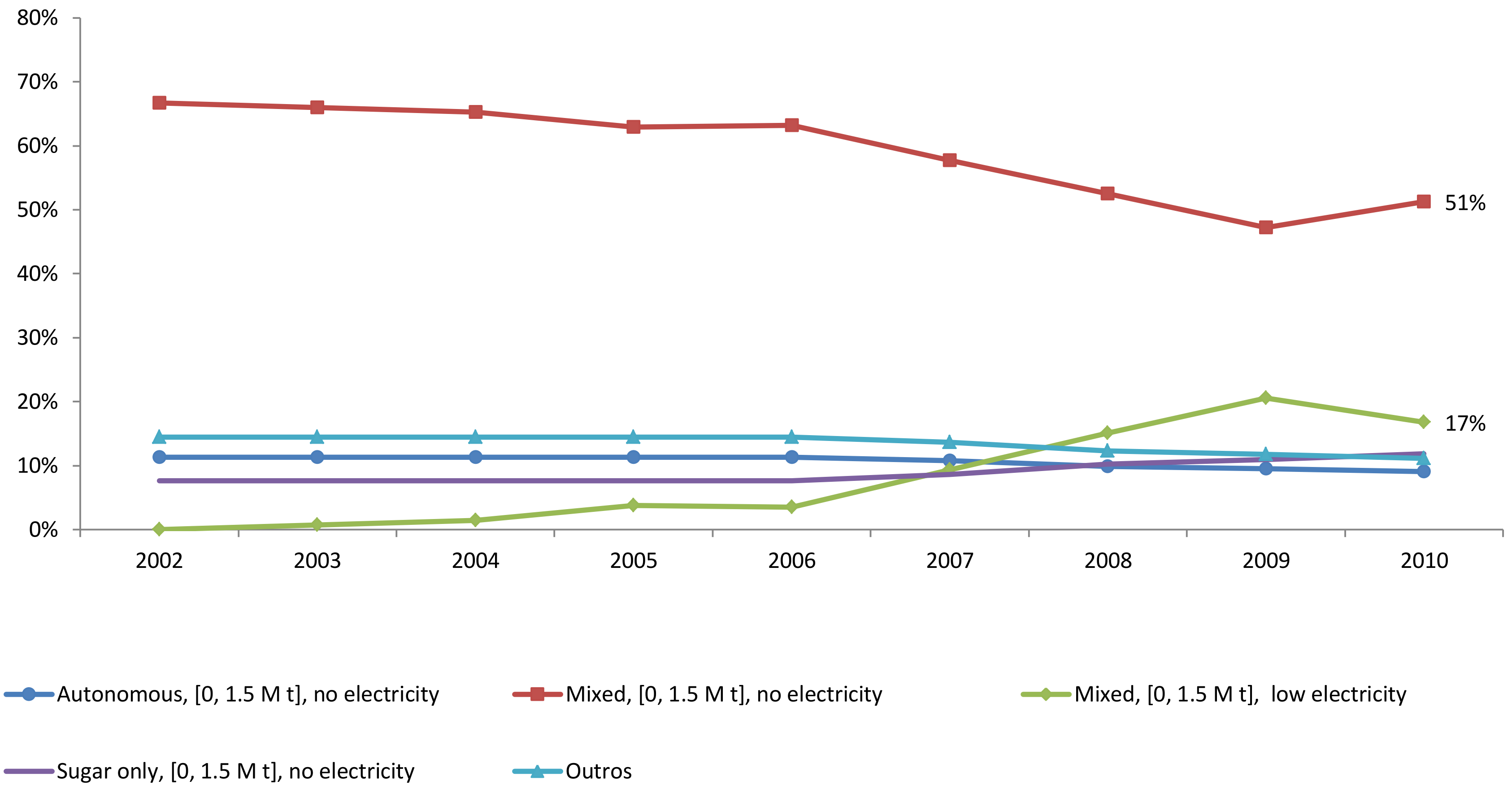
Regional industry profile: Center-west Cerrado



Regional industry profile: North Amazon



Regional industry profile: Northeast Coast



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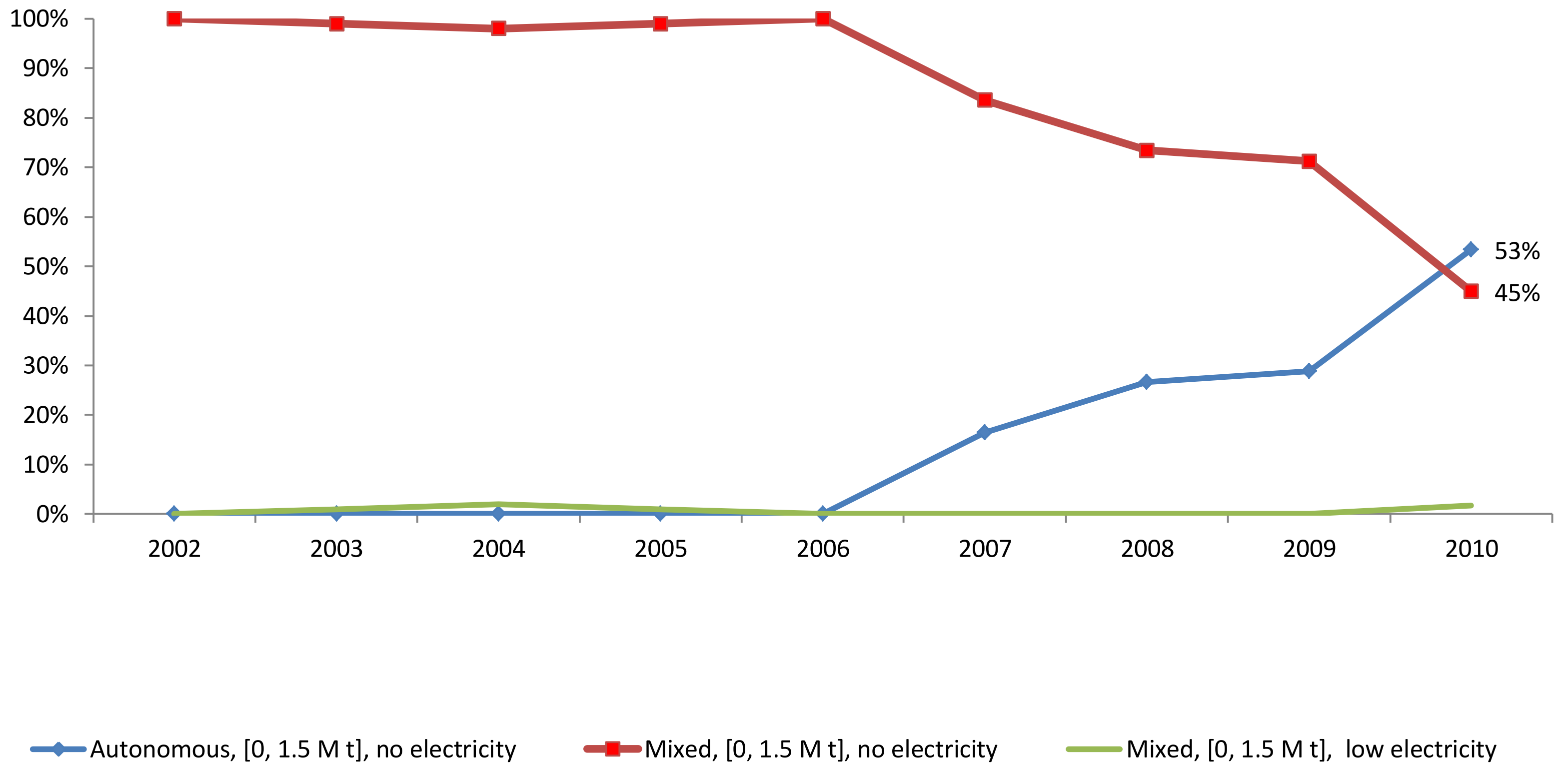
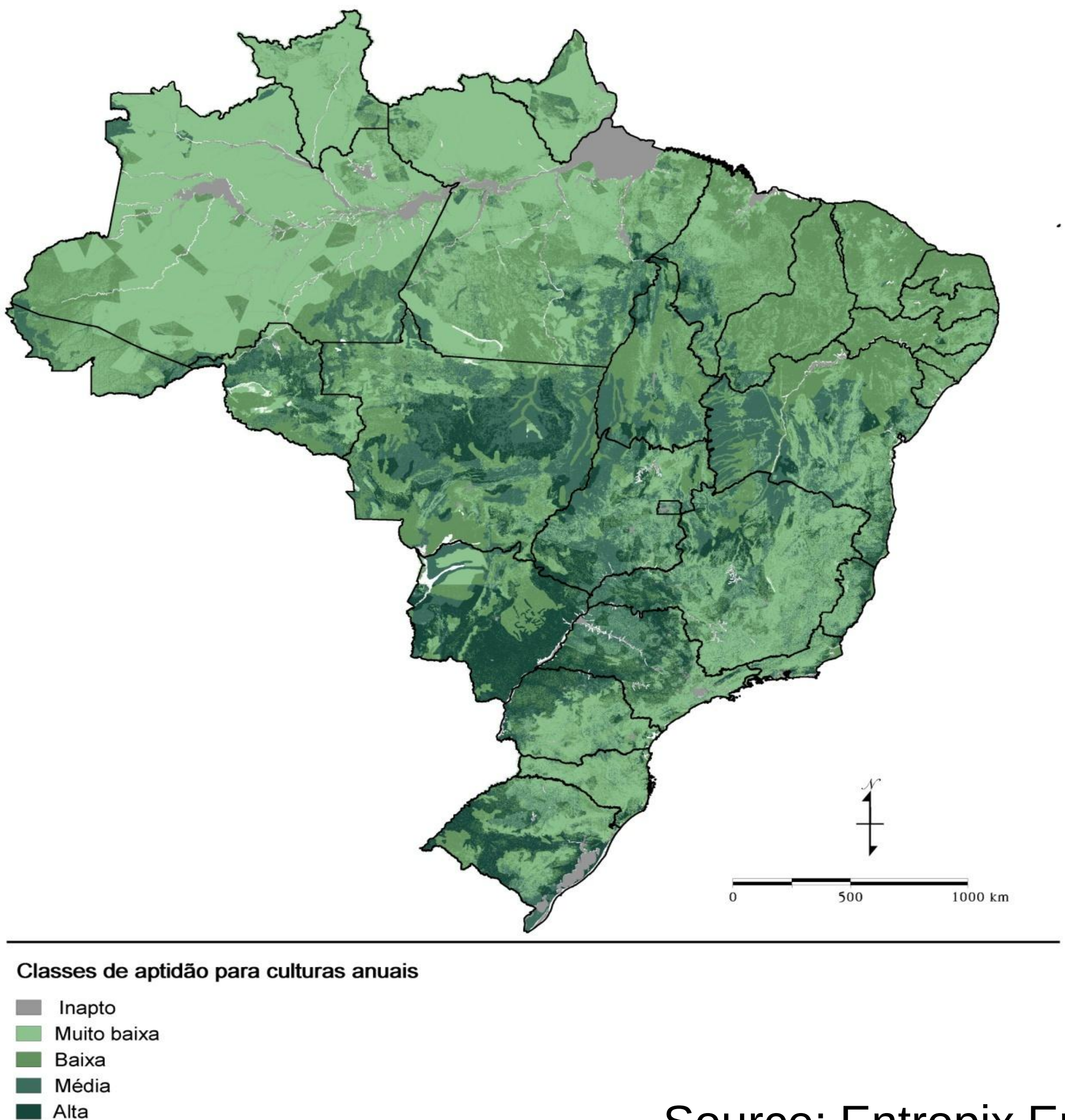
Regional industry profile: Center-west Cerrado



GIS Database in BLUM – Suitability for Annual Crops



Source: Entropix Engenharia.

Deforestation on the Cerrado Biome

Polygons with deforestation characterized with agriculture or pasture (hectares, 2006/07)

State	Agriculture (ha)	Pasture (ha)	Total (ha)	% of total area	% agriculture	% pasture
BA	55,242	15,889	71,130	0.47%	78%	22%
GO	17,808	28,095	45,904	0.14%	39%	61%
MA	16,998	10,674	27,672	0.13%	61%	39%
MG	9,584	18,403	27,986	0.08%	34%	66%
MS	8,318	30,665	38,982	0.18%	21%	79%
MT	76,967	96,315	173,282	0.48%	44%	56%
PI	38,163	7,358	45,521	0.49%	84%	16%
SP	4,955	2,793	7,748	0.10%	64%	36%
TO	8,336	35,137	43,473	0.17%	19%	81%
Total	**236,371**	**245,329**	**481,698**	**2.24%**	**47%**	**53%**

State	Agriculture (ha)	Pasture (ha)	Total (ha)	% of total area	% agriculture	% pasture
BA	83,404	8,648	92,052	0.61%	91%	9%
GO	6,756	29,525	36,281	0.11%	19%	81%
MA	20,196	17,580	37,775	0.18%	53%	47%
MG	27,253	44,735	71,988	0.22%	37%	63%
MS	28,609	19,991	48,600	0.22%	59%	41%
MT	35,501	31,755	67,256	0.19%	52%	48%
PI	27,000	1,064	28,064	0.30%	96%	4%
SP	3,848	0	3,848	0.05%	100%	0%
TO	7,961	50,508	58,469	0.23%	13%	87%
Total	**240,528**	**203,806**	**444,334**	**2.10%**	**54%**	**46%**

Source: ICONE (original GIS data from LAPIG)

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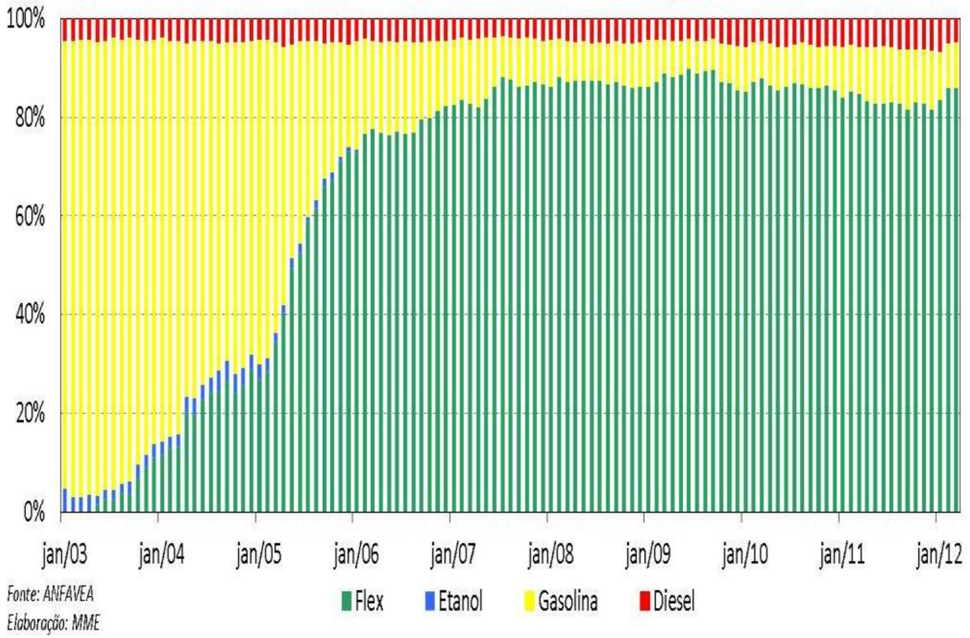
Methodology for Elasticities' Calculation

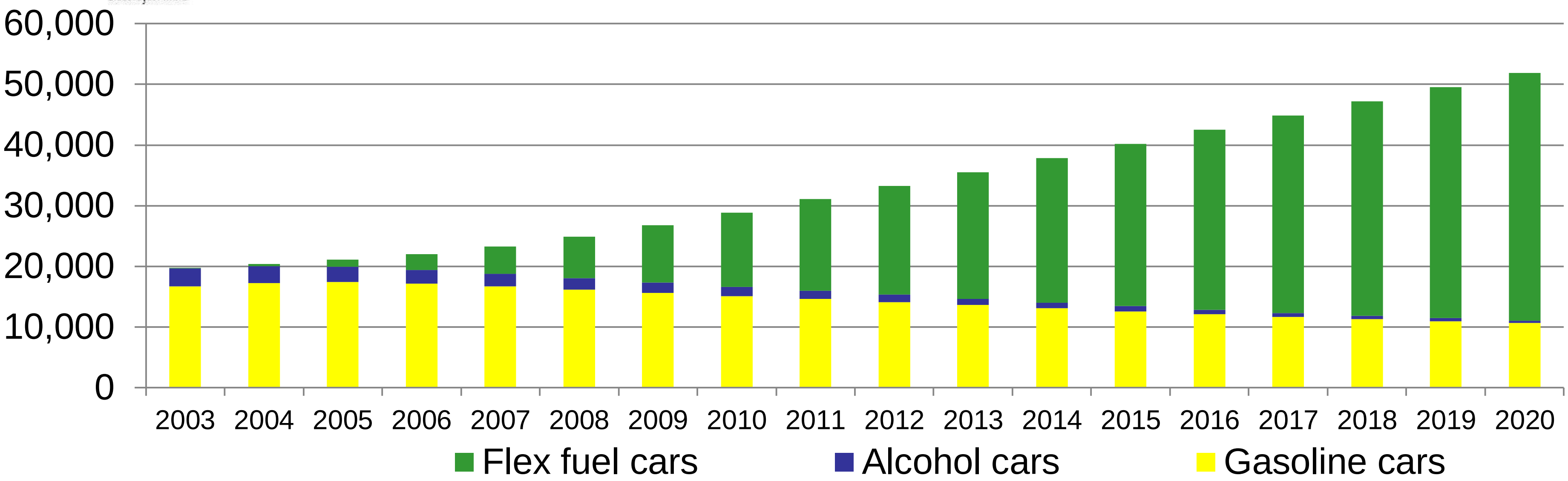
- Calculating Land Supply Elasticities for each region
  - Deforestation of the Cerrado and Amazon biomes combined with positive variation of profitabilities – all regions except Northeast Coast
  - Northeast Coast was calculated using total agricultural land for the period
  - Elasticities at the point, average of the period 2002-2009
- Own Elasticities based on the literature
- Competition Elasticities Matrices: calculated using competition ranking for each region
  - Example for competition ranking for the Center-West Cerrado Region

	1	2	3	4	5	6
Corn	Soybean	Pasture	Rice	Dry Bean	Cotton	Sugarcane
Soybean	Pasture	Corn	Rice	Dry Bean	Cotton	Sugarcane
Cotton	Pasture	Soybean	Corn	Dry Bean	Rice	Sugarcane
Rice	Pasture	Soybean	Corn	Dry Bean	Cotton	Sugarcane
Dry Bean	Corn	Soybean	Pasture	Rice	Cotton	Sugarcane
Sugarcane	Pasture	Corn	Soybean	Rice	Cotton	Dry Bean
Pasture	Soybean	Corn	Rice	Cotton	Dry Bean	Sugarcane

Source: calculated by the authors

Sugarcane technology: type of vehicle





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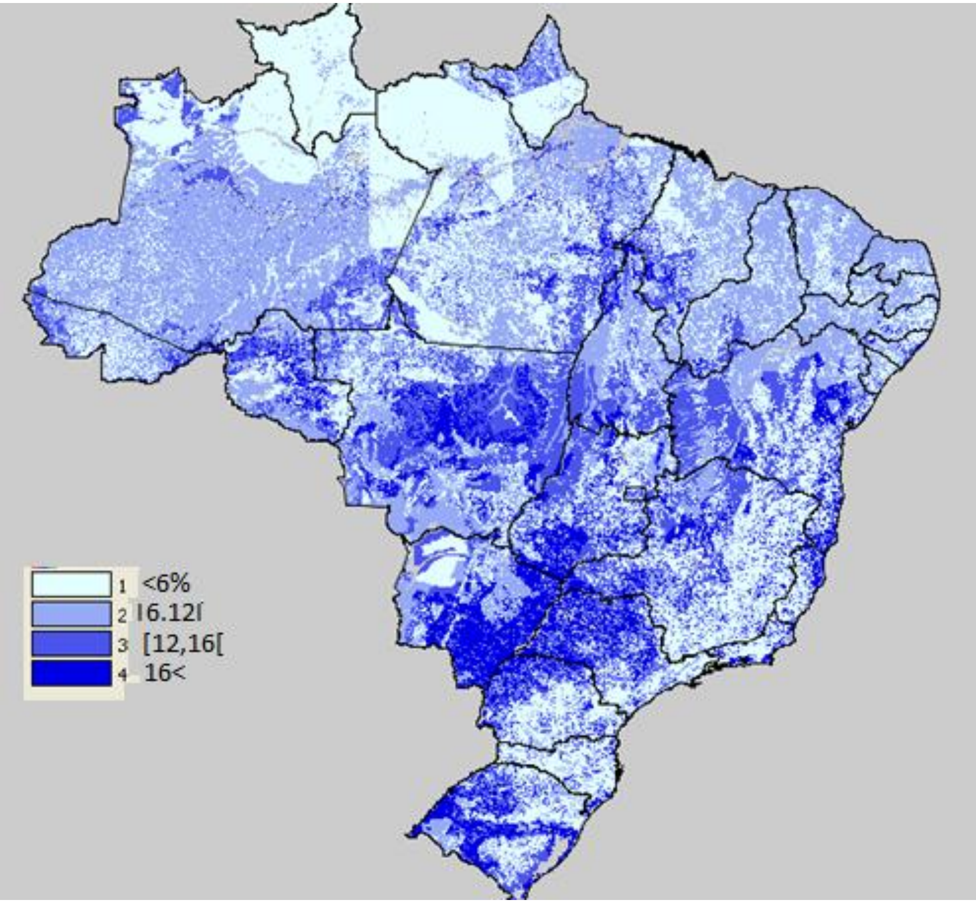
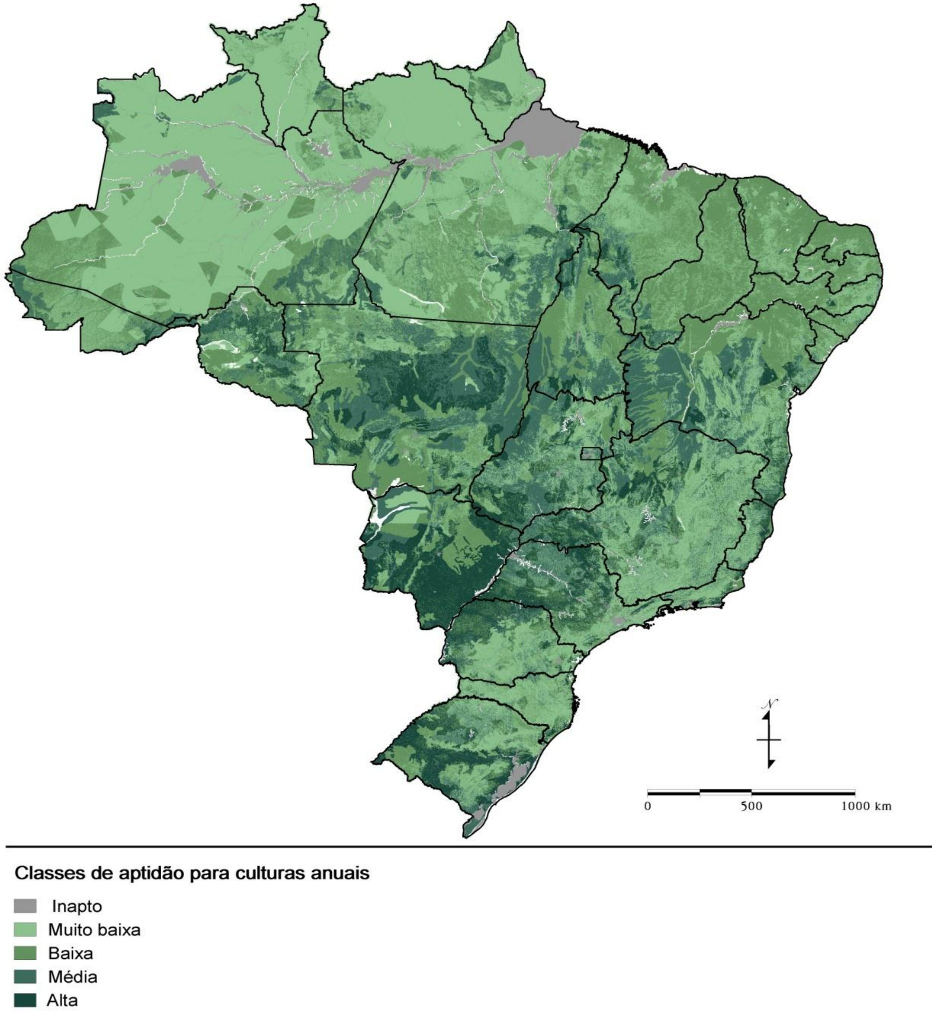
Land use and land availability

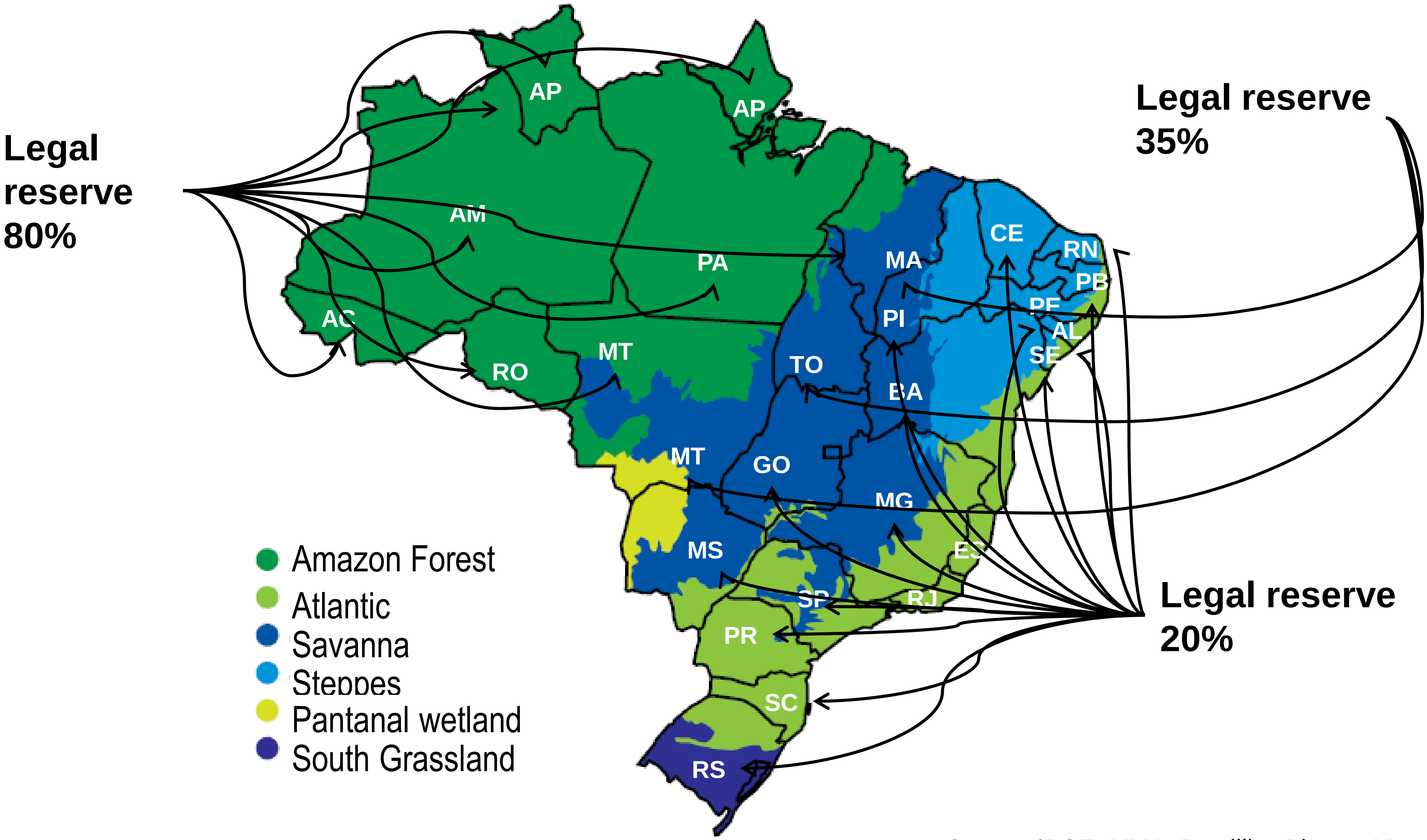
Land Suitability: topography





Source: ESALQ, *AgLUE*-BR

Brazilian Biomes and Legal Reserve (preservation rates)



Source: IBGE, MMA. Brazillian Biomes Map.

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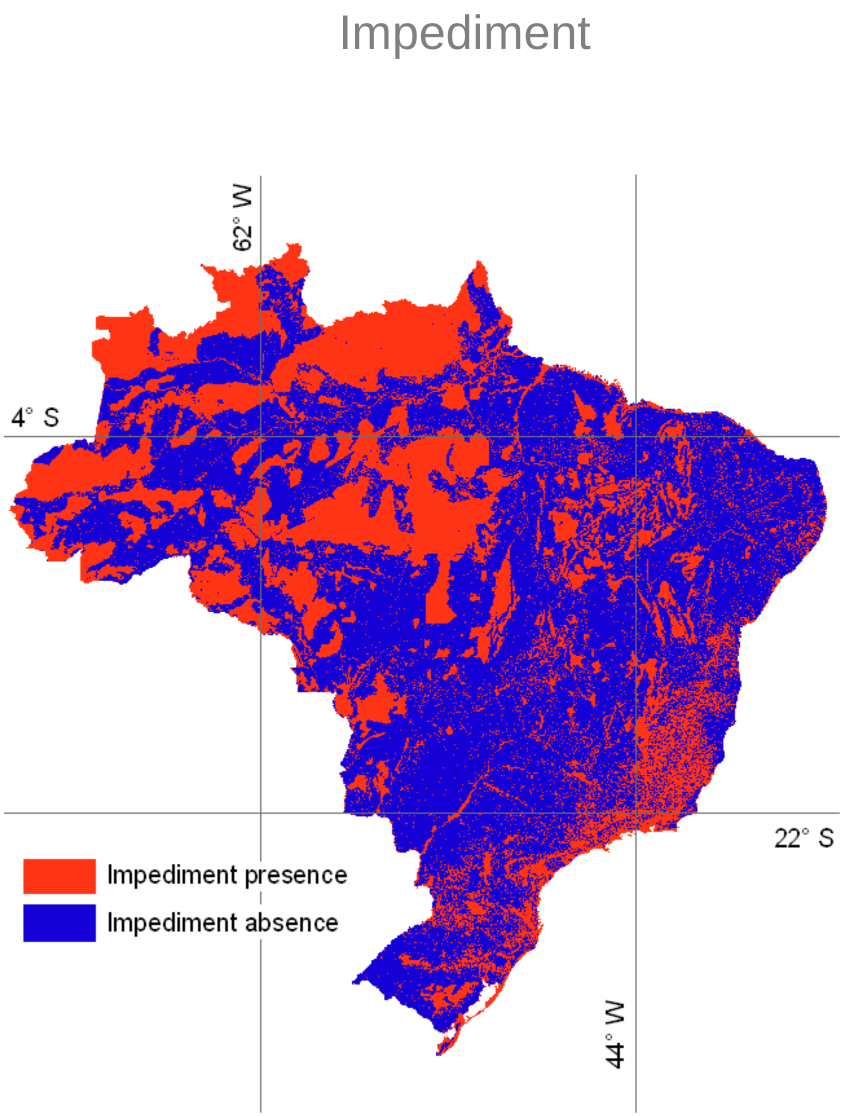
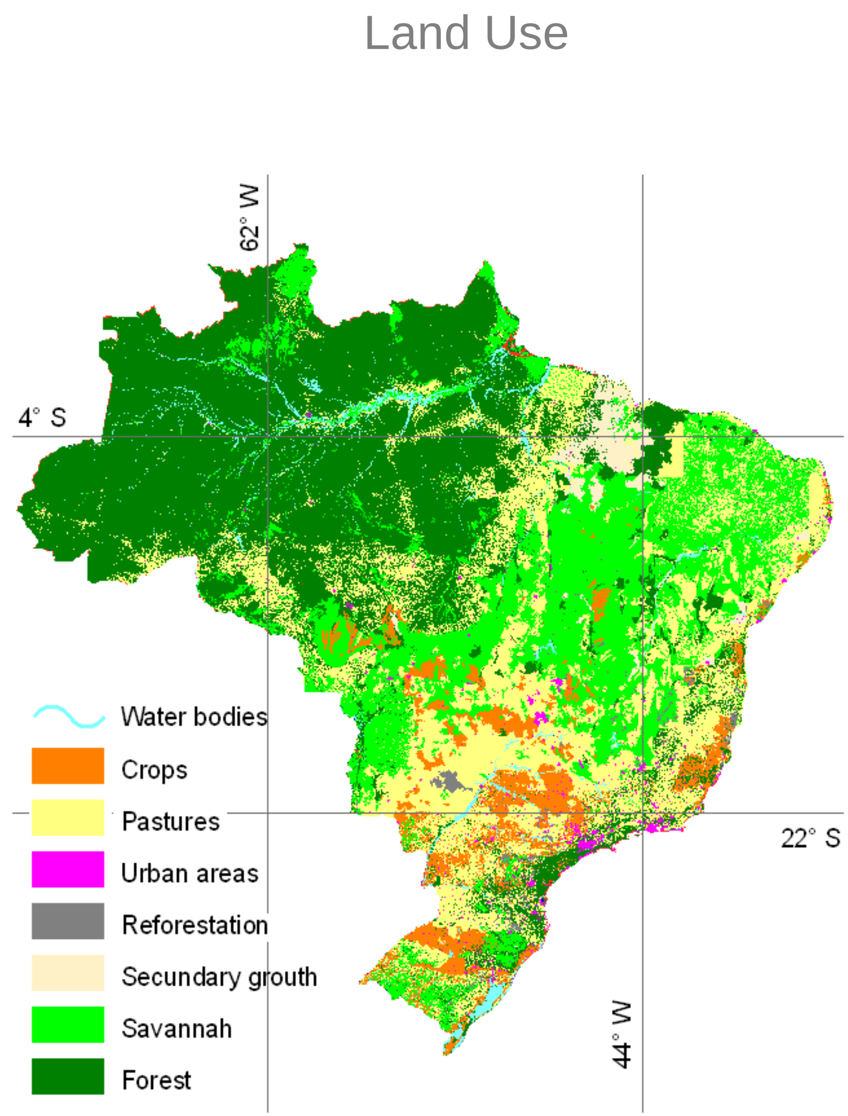
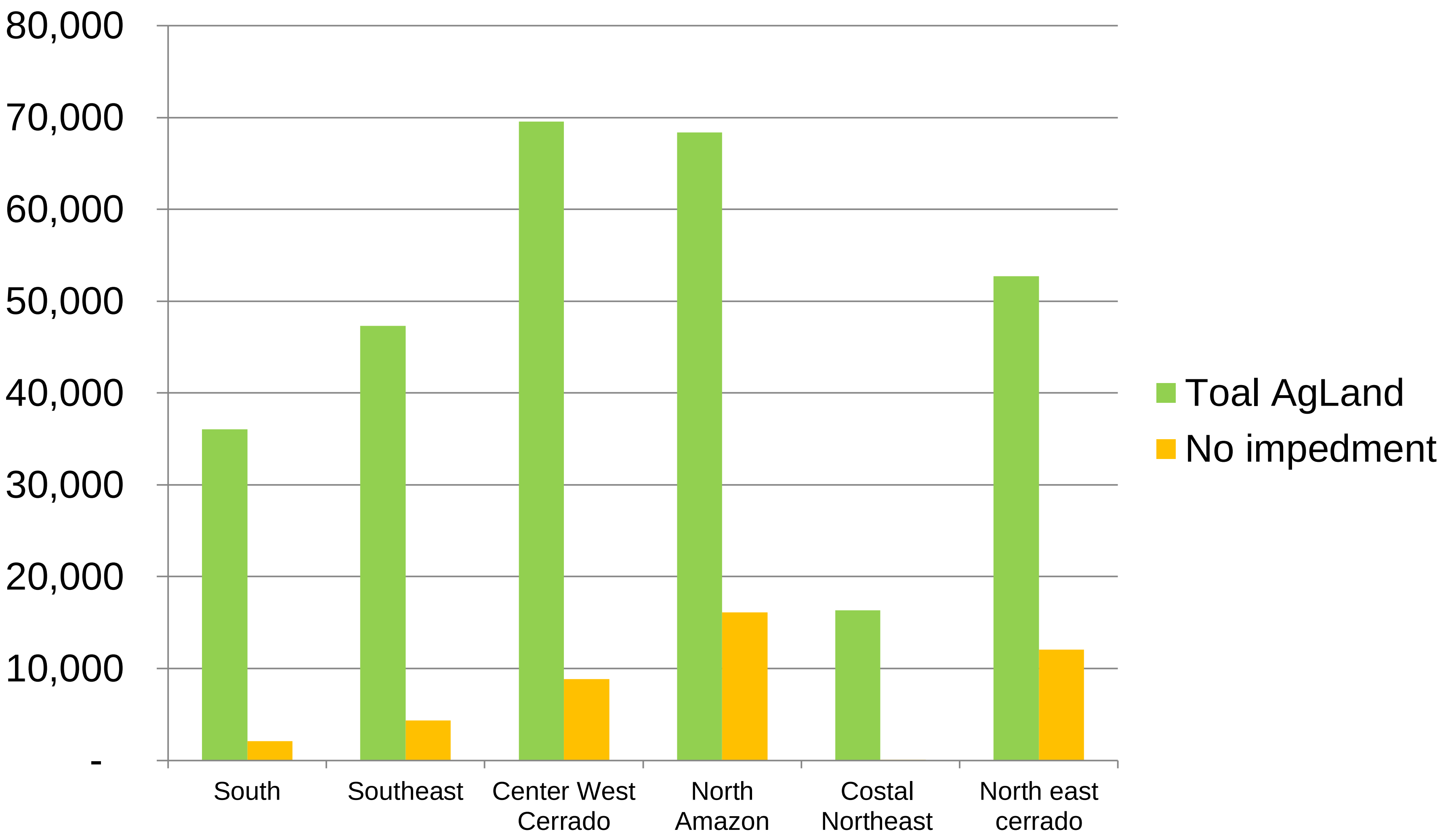
GIS Database on Land Use in BLUM





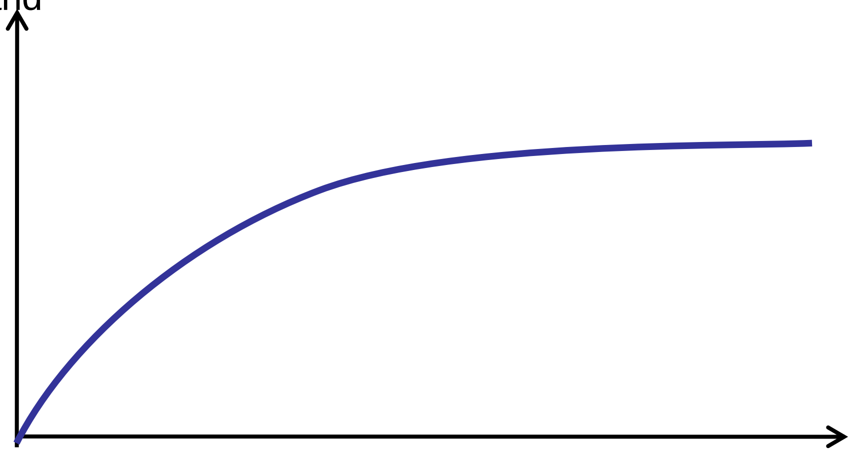
Source: Brazilian Low Carbon Study, The World Bank.

Total land used for agriculture and land with no impediments for agricultural expansion



Land Supply Curve and Elasticities

Total area used for Agriculture is defined by the Agland elasticity (scale effect)



- The share of total area that is dedicated to agricultural production follows a function such as:

$$m_{lt} = \frac{A_{lt}}{A_l^T} = kr_{lt}^{\varepsilon_\eta^{A_l}} \Rightarrow m_{lt} = \frac{A_{lt}}{A_l^T} = kr_{lt}^{\alpha_{lt}\varepsilon_\eta^{A_l}} \quad \text{Where: } \alpha_{lt} = 1 - \frac{A_{lt} - A_{l0}}{A_l^T}$$

k is a parameter to be defined, r_t is the average revenue of the region, ε is the land supply elasticity. The parameter α_{lt} is positive, higher or lower than one and is defined in each t.

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Land use change

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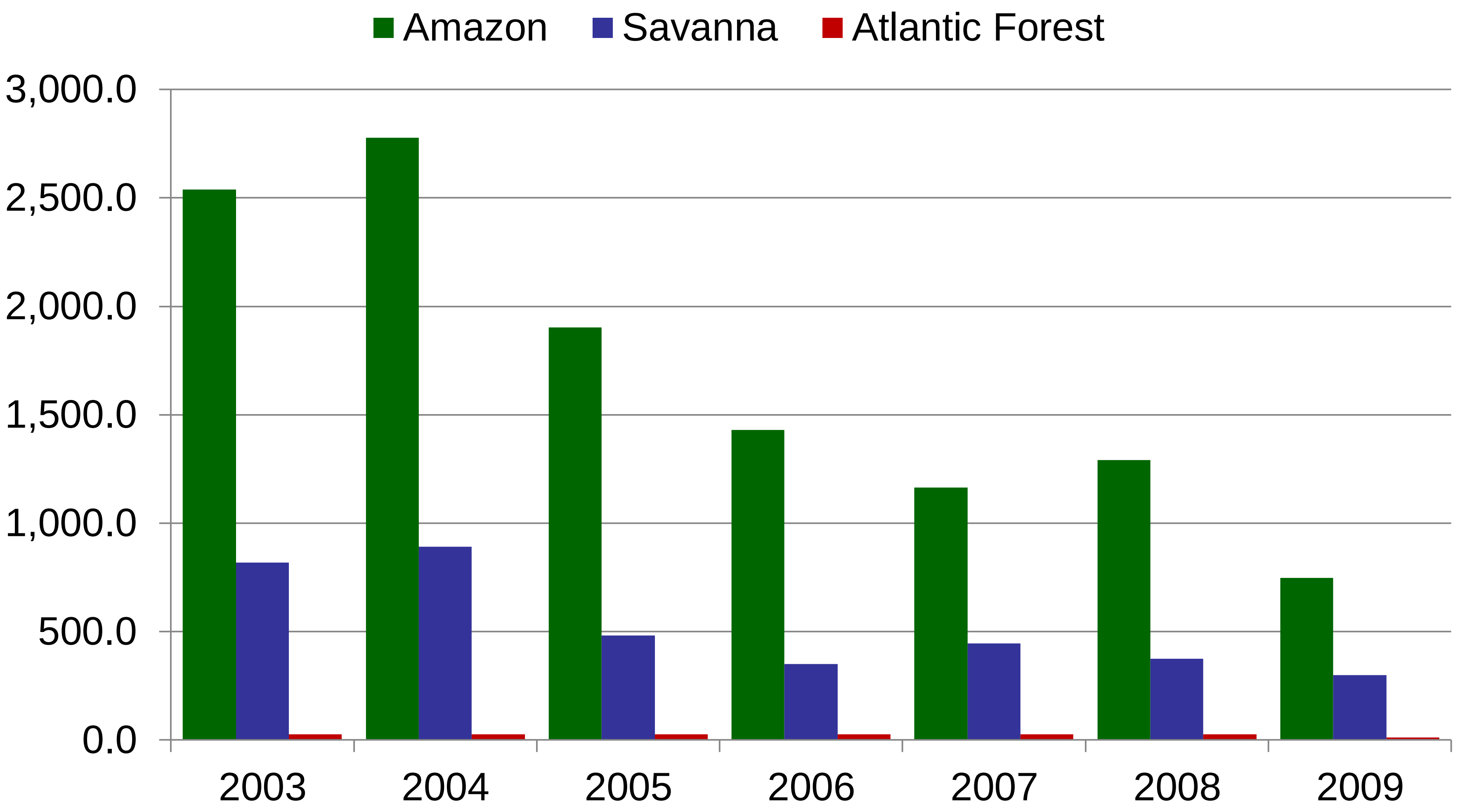
Accumulated Deforestation
(1,000 hectares)



Source: LAPIG/UFG, PRODES/INPE, SOS Mata Atlântica, MMA