Integrating Life-Cycle Assessment and Input-Output analysis for the assessment of ethanol greenhouse gases emissions in Brazil

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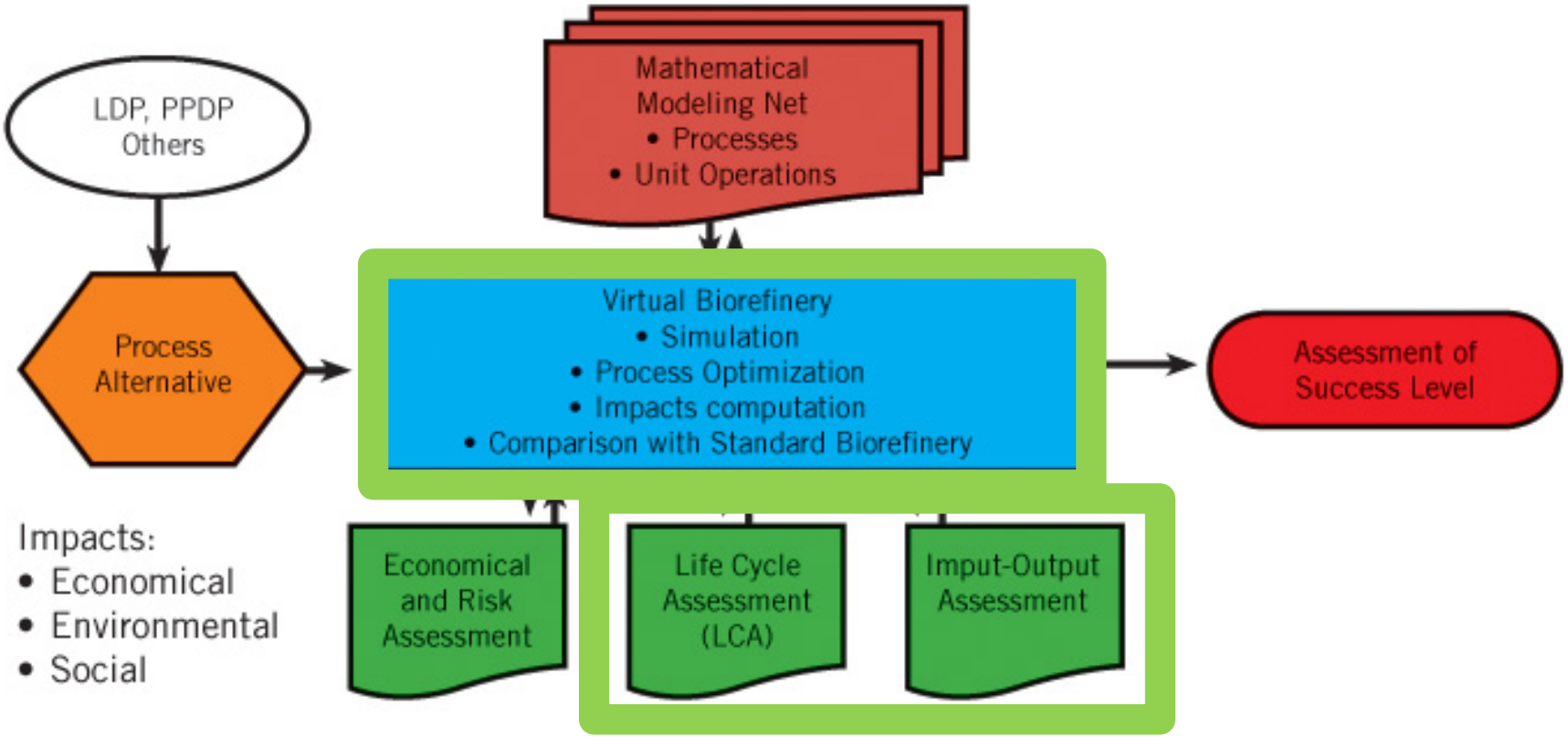
Virtual Sugarcane Biorefinery methods

- **Currently:** LCA and Input-Ouput Analysis (IOA) are stand-alone methods
- **Objective: to integrate LCA and IOA**



Advantages of LCA-IOA

Life Cycle Assessment (LCA)

(+) **Bottom-up analysis**

(+) Life cycle inventory: **process-based**

(+) Allow to **compare** similar products

Input-Output Analysis (IOA)

(+) **Top-down technique:** input-output table

(+) **System boundary**: Brazilian economy sectors

(+) Measure **direct and indirect** impacts

Integration LCA-IOA

Life Cycle Assessment

- Aspen Plus®
- CanaSoft
- Usage speadsheet

Life Cycle Inventory

Process-based data are inserted into the input-output table

Tiered hybrid IOA:

- Sugarcane and ethanol sectors
  CanaSoft : sugarcane
  Econosoft e Aspen: ethanol

		Setores						Demanda final	Valor produção
								Y	X
		1	2	...	j	...	55		
Setores	1	z_{11}	z_{12}		z_{1j}		$z_{1,55}$		
	2	z_{21}	z_{22}		z_{2j}		$z_{2,55}$		
	...	...	...		...		...		
	i	z_{i1}	z_{i2}		z_{ij}		$z_{i,55}$		
	...	...	...		...		...		
	55	z_{n1}	z_{n2}		z_{nj}		$z_{55,55}$		
Valor adicionado	W								
Valor da produção	X				Xj				

- **T**echnology scenarios
- **D**irect and indirect impacts
- **E**conomic and environmental indicators

Starting point: Input-Output table

		Sugarcane						Final Demand	Total output
								Y	X
		1	2	...	j	...	55		
Fertilizer	1								
	2								
	...								
	...								
	55								
Value added	W								
Total purchases	X				100				

Matrix A

Direct requirement: $a_{ij} = z_{ij}/X_j$

= 0,05

For each $ 1 worth of sugarcane , there was $ 0.05 worth due to fertilizer purchases

Input-output analysis

Technical coefficient matrix (A), final demand (Y) and total output (X):

$$\sum_{j=1}^{n} a_{ij} X_j + Y_i = X_i$$

$$AX + Y = X$$

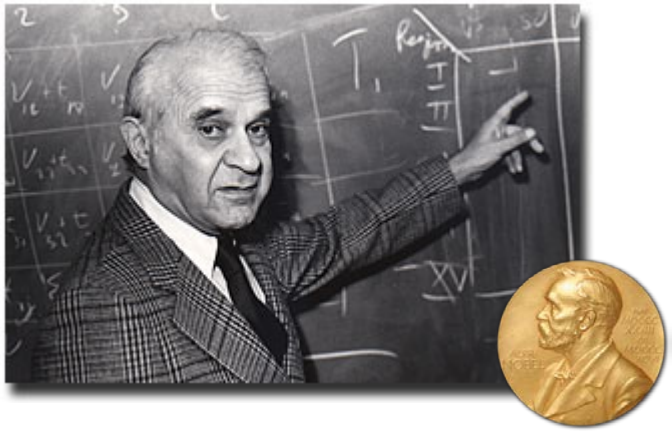
$$X = (I - A)^{-1} Y$$

Output array with values for each sector

"Leontief Inverse matrix"

Final demand array (consumption from families, government, etc.)

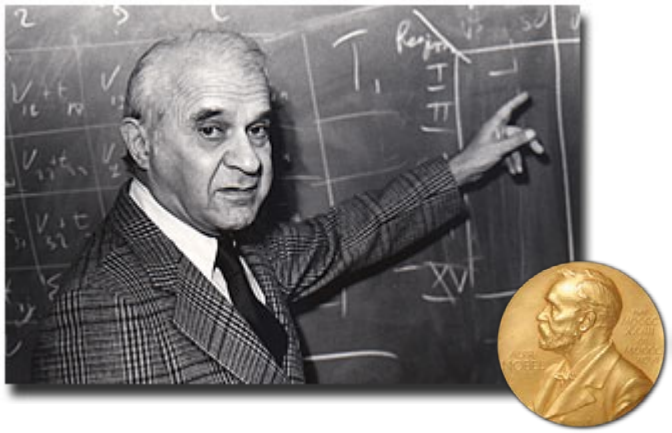
Wassily Leontief (1905-1999)



Nobel prize in Economics (1973)

Input-output analysis

Wassily Leontief (1905-1999)



Nobel prize in Economics (1973)

$$X = (I - A)^{-1} Y$$

Leontief inverse equals the following power series:

$$X = IY + AY + A^2Y + A^3Y + \ldots$$

$$X = [I + A + A^2 + A^3 + \ldots]Y$$

$$X = [I + A]Y \quad + \quad [A^2 + A^3 + \ldots]Y$$

Direct impact **Indirect impact**

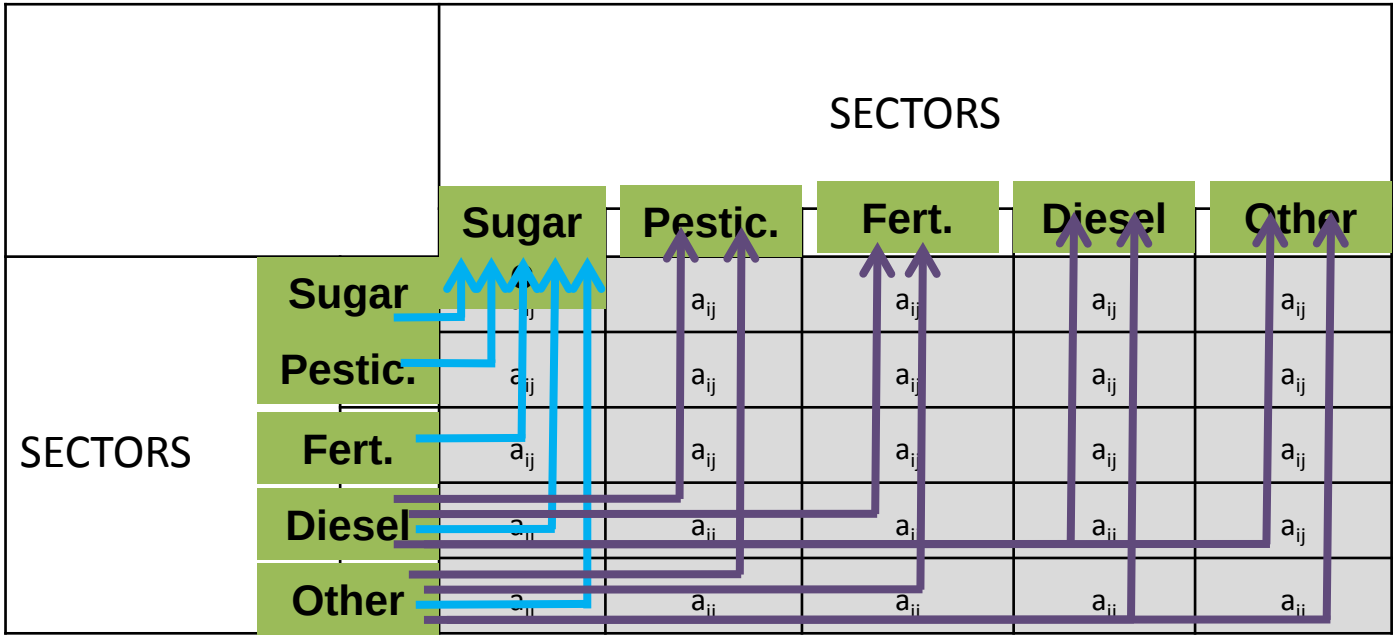
Input-output analysis

$$X = [I + A]Y$$ + $$X = [A^2 + A^3 + \ldots + A^n]Y$$

DIRECT:
For instance:
Inputs to sugarcane

INDIRECT: Inputs to the inputs

Sum up infinite round-by-round effects ($n \to \infty$), A^n tends to zero.



IOA similarity to LCA

$$X = [I + A]Y + X = [A^2 + A^3 + \ldots + A^n]Y$$

List of required inputs:

Diesel

Sugarcane

Ethanol

Gasoline

Inorganic chemicals

Petroleum and natural gas

Cement

Fuel oil

Other non-metallic mineral products

Other refined petroleum products

Etc....

Similar to the Life Cycle Inventory (LCI)

Objectives

$$X = (I - A)^{-1} Y$$

Shock in
"Final demand"

Technology scenario

- 1G sugarcane ethanol (2009)
- 1G sugarcane ethanol (optimized),
- 1G2G sugarcane ethanol.

To measeure impacts to the whole country considering the entire supply chain

- Economic
- Environmental (GHG emission)

Main Steps (4):

1

		Setores de compra						Demanda final	Valor produção
		1	2	...	j	...	73	Y	X
Produtos vendidos	1	z_{11}	z_{12}		z_{1j}		$z_{1\text{-}73}$		
	2	z_{21}	z_{22}		z_{2j}		$z_{2\text{-}73}$		
	...	...	...		...		...		
	i	z_{i1}	z_{i2}		z_{ij}		$z_{i\text{-}73}$		
	...	...	...		...		...		
	120	z_{n1}	z_{n2}		z_{ni}		$z_{120\text{-}73}$		
Valor adicionado	W								
Despesas totais	X^T								

Direct requirements matrix (A)

2

Shock in final demand (Y)

$$X = (I - A)^{-1}.Y$$

3

		Setores de compra						Demanda final	Valor produção
		1	2	...	j	...	73	Y	X
Produtos vendidos	1	z_{11}	z_{12}		z_{1j}		$z_{1\text{-}73}$		
	2	z_{21}	z_{22}		z_{2j}		$z_{2\text{-}73}$		
	...	...	...		...		...		
	i	z_{i1}	z_{i2}		z_{ij}		$z_{i\text{-}73}$		
	...	...	...		...		...		
	120	z_{n1}	z_{n2}		z_{ni}		$z_{120\text{-}73}$		
Valor adicionado	W								
Despesas totais	X^T								

Impact on the outputs array (X)

4

Evironmental burdens array (R)

		Setores de compra						Demanda final	Valor produção	Carga ambiental
		1	2	...	j	...	73	Y	X	
Produtos vendidos	1	z_{11}	z_{12}		z_{1j}		$z_{1\text{-}73}$			
	2	z_{21}	z_{22}		z_{2j}		$z_{2\text{-}73}$			
	...	...	...		...		...			
	i	z_{i1}	z_{i2}		z_{ij}		$z_{i\text{-}73}$			
	...	...	...		...		...			
	120	z_{n1}	z_{n2}		z_{ni}		$z_{120\text{-}73}$			
Valor adicionado	W									
Despesas totais	X^T									

$$E = R.X$$

Environmental impact (E)

Scenarios LCA-IOA

I) **1G 2009** : sugarcane ethanol production, Brazilian average technology in 2009

II) **1G optimized**: biorefinery featuring the best current 1G technologies for ethanol and electricity production;

III) **1G2G:** biorefinery featuring the best upcoming 1G2G technologies for ethanol and electricity production;

Scenarios LCA-IOA

- **1G:**

	1G-2009	1G optimized	Reference
Agricultural data: Canasoft			
Sugarcane yield	**81.9 TC/ha**	81.9 TC/ha	CONAB (2009)
Harvesting technology	**52.1% manual**	0% manual	CONAB (2009)
Mechanical harvesting	**25.3% burning**	0% burning*	*Assumed
Sugarcane straw yield	**140 kg/TC**	140 kg/TC	Dias et al. (2011)
Straw removal	**0%**	50% (integral, no baling)	Report PAT (2012)
Vinasse	**888 kg/TC**	888 kg/TC	Report PAT (2012)
Industrial data: Aspen e Econosoft			
Distillery configuration	Stand-alone	**Stand-alone**	Assumido
Ethanol dehydration	Azeotropic distilaltion	**Molecular sieves**	Cavalett et al. (2012)
Steam consumption	Simulated	**20% reduction**	Cavalett et al. (2012)
Drivers	Mechanical (direct)	**Electric**	Cavallet et al. (2012)
Boilers	22 bar	**90 bar**	Cavallet et al. (2012)
Bagasse surplus	Sold	**Electricity production**	Cavallet et al. (2012)
Electricity surplus	-	**183 kWh/TC**	Cavallet et al. (2012)
Ethanol yield	64.7 kg/TC	**64.8 kg/TC**	Cavallet et al. (2012)

Scenarios LCA-IOA

- **1G2G:**

	Integrated1G2G
Agricultural data	
Sugarcane yield	81.9 TC/ha
Mechanical harvesting area	100 %
Straw yield	140 kg/TC
Straw removal from field	50 % (integral, no bailing)
Vinasse yield	1175 kg / TC
Industrial data	
Distillery configuration	Stand-alone
1G Ethanol production	Optimized
Drivers	Electric
Ethanol dehydration	Molecular sieves
Steam consumption	20% reduction
Boilers	90 bar
Ethanol yield	**92.3 kg/TC**
Electricity surplus	**80 kWh/TC**
Pretreatment	**Steam explosion**
Hidrolysis	**Future technology**
Hydrolysis yield	**70%**
Solids loading	**15%**
Hydrolysis reaction time	**48h**
Pentose biodigestion	**Yes**

Source: Dias et al. (2011) e PAT (2012).

Preliminary Results IOA-LCA

Direct requirements

1

		Setores de compra						Demanda final	Valor produção
		1	2	...	j	...	73	Y	X
Produtos vendidos	1	z_{11}	z_{12}		z_{1j}		$z_{1\cdot73}$		
	2	z_{21}	z_{22}		z_{2j}		$z_{2\cdot73}$		
	...	...	...		...		...		
	i	z_{i1}	z_{i2}		z_{ij}		$z_{i\cdot73}$		
	...	...	...		...		...		
	120	z_{n1}	z_{n2}		z_{nj}		$z_{120\cdot73}$		
Valor adicionado	W								
Despesas totais	X^t								

Direct requirements matrix (A)

Direct requirements

Agricultural stage (sugarcane) : Canasoft®

Lista de itens na composição de custos (Canasoft)		
Maquinário	479,01	R$/(ha.ano)
Implementos	190,37	R$/(ha.ano)
Diesel	325,50	R$/(ha.ano)
Manutenção	44,12	R$/(ha.ano)
Lubrificantes	4,85	R$/(ha.ano)
Seguro e Garagem	13,39	R$/(ha.ano)
Mão de obra (operações mecanizadas)	115,74	R$/(ha.ano)
Mão de obra (operações manuais)	221,60	R$/(ha.ano)
Mudas	186,57	R$/(ha.ano)
Agroquímicos	210,06	R$/(ha.ano)
Fertilizantes (N, P e K)	479,47	R$/(ha.ano)
Calcário e gesso	38,12	R$/(ha.ano)
Caminhões	303,70	R$/(ha.ano)
Reboques	80,19	R$/(ha.ano)
Diesel	336,33	R$/(ha.ano)
Pneus	101,26	R$/(ha.ano)
Manutenção	41,37	R$/(ha.ano)
Lubrificantes	4,55	R$/(ha.ano)
Mão de obra (motoristas)	77,58	R$/(ha.ano)
Eletricidade recalque vinhaça	10,16	R$/(ha.ano)

Agrupamento: itens idênticos (Canasoft)		
Maquinário	479,01	R$/(ha.ano)
Implementos	190,37	R$/(ha.ano)
Diesel (total)	689,50	R$/(ha.ano)
Manutenção (total)	85,49	R$/(ha.ano)
Lubrificantes (total)	9,40	R$/(ha.ano)
Seguro e Garagem	13,39	R$/(ha.ano)
Mudas	186,57	R$/(ha.ano)
Agroquímicos	210,06	R$/(ha.ano)
Fertilizantes (N, P e K)	479,47	R$/(ha.ano)
Calcário e gesso	38,12	R$/(ha.ano)
Caminhões	303,70	R$/(ha.ano)
Reboques	80,19	R$/(ha.ano)
Pneus	101,26	R$/(ha.ano)
Eletricidade	10,16	R$/(ha.ano)
Concreto (total)	4,45	R$/(ha.ano)
Aço estrutural	3,26	R$/(ha.ano)
Impermeabilizante asfáltico (total)	11,32	R$/(ha.ano)
Transporte	0,66	R$/(ha.ano)
Outros custos de construção (total)	2,52	R$/(ha.ano)
Sistema de recalque vinhaça	2,26	R$/(ha.ano)

Código por produto (Matriz IBGE, 110 produtos e 55 setores)	
EOB	Excedente operacional bruto
EOB	Excedente operacional bruto
030905	Óleo diesel
110101	Serviços de manutenção e reparação
030906	Outros produtos do refino de petróleo e coque
090101	Intermediação financeira, seguros e previdência complementar e serviços rel
010104	Cana de açúcar
031401	Defensivos agrícolas
031101	Produtos químicos inorgânicos
020303	Outros produtos de minerais não-metálicos
070101	EOB
070101	EOB
031801	Artigos de borracha
040101	Produção e distribuição de eletricidade, gás, água, esgoto e limpeza urbana
031901	Cimento
032301	Produtos de metal - exclusive máquinas e equipamento
030906	Outros produtos do refino de petróleo e coque
070101	Transporte de carga
050101	Construção civil
032301	Produtos de metal - exclusive máquinas e equipamento

Direct requirements

Industrial stage: Econosoft®, Aspen Plus®

Coeficientes da Planilha Econômica (T.I.R)	
Cana-de-açúcar	0,304
Palha	0,019
Enzimas	0,012
Outros insumos	0,082
Imposto sobre a produção	0,007
Mão-de-obra	0,022
Excedente operacional bruto	0,554
	1,000

Desagregando outros insumos (ICV e Aspen)	
Cana-de-açúcar	0,3037
Palha	0,0192
Enzimas	0,0115
Sulphuric acid, liquid, at plant, market mix/CTBE B	0,0240
Lubricating oil, market mix/CTBE BR U	0,0045
Lime, hydrated, packed, at plant/CH U	0,0175
Zeolite, powder, at plant/RER S	0,0070
Chemicals organic (antibiotic), at plant/GLO U	0,0252
Chemicals inorganic (floculant), at plant/GLO U	0,0040
Imposto de Renda - Pessoa Jurídica	0,0065
Mão-de-obra	0,0224
Excedente operacional bruto	0,5544

Código por produto (110 produtos e 55 setores)	
010104	Cana de açúcar
010104	Cana de açúcar
031701	Produtos e preparados químicos diversos
031101	Produtos químicos inorgânicos
030906	Outros produtos do refino de petróleo e coque
031101	Outros produtos de minerais não metálicos
031701	Produtos e preparados químicos diversos
031301	Produtos farmacêuticos
031701	Produtos e preparados químicos diversos
	Impostos diretos
	Remunerações
	Excedente operacional bruto

Direct requirments matrix

"A" Matrix : 65 columns (sectors) and 120 rows (products)

Matriz coeficientes		Sucra	SucraP 1G2009	SucraP 1Gotm	SucraP1G2G	Cana	CanaP 1G2009	CanaP 1Gotim	Cana-P 1G2G	Elet. Gerada norta da economia	Transmissao e Distribuição	Agricultura, silvicultura, exploração florestal	Pecuária e pesca	Petróleo e gás natural	Minério de ferro	Outras ind. extrativas	Alimentos e Bebidas	Produtos do fumo	Têxteis	Artigos de vestuário e acessórios	Artefatos de couro e calçados	Produtos madeira, exclusive móveis
		S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}	S_{17}	S_{18}	S_{19}	S_{20}	S_{21}
Cana	P_1	0,3583	0	0	0	0,0129	0	0	0	0,0000	0,0000	0,0019	0,0007	0	0	0	0,0279	0	0	0	0	0
Cana 1G 2009	P_2	0	0,4569	0	0	0	0,0424	0	0	0,0000	0	0	0	0	0	0	0	0	0	0	0	0
Cana-P 1G otimizada	P_3	0	0	0,3686	0	0	0	0,0425	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cana-P 1G2G	P_4	0	0	0	0,3102	0	0	0	0,0428	0	0	0	0	0	0	0	0	0	0	0	0	0
Etanol	P_5	0,0031	0	0	0	0,0012	0	0	0	0,0000	0,0000	0,0005	0,0006	0	0	0,0017	0,0001	0	0,0004	0,0002	0	0
Etanol 1G 2009	P_6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Etanol P 1G otm	P_7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Etanol-P 1G 2G	P_8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Açúcar	P_9	0,1370	0	0	0	0,0003	0	0	0	0,0000	0,0015	0,0002	0,0000	0,0000	0,0001	0,0000	0,0128	0,0000	0,0001	0,0000	0,0000	0,000
Eletric. Gerada	P_{10}	0,0036	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,3481	0,00032	0,00000	0,00013	0,00324	0,00000	0,00026	0,00000	0,00044	0,00000	0,00000	0,003
Eletric. Gerada 1G otimizad	P_{11}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eletricidade 1G2G	P_{12}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eletric. Distribuída	P_{13}	0,0017	0	0	0	0,0054	0	0	0	0,0000	0,0000	0,0054	0,0000	0,0388	0,0184	0,0000	0,0137	0,0000	0,0219	0,0000	0,0000	0,010
Arroz em casca	P_{14}	0,0000	0	0	0	0,0067	0	0	0	0,0000	0,0000	0,0067	0,0012	0,0000	0,0000	0,0000	0,0210	0,0000	0,0000	0,0000	0,0000	0,000
Milho em grão	P_{15}	0,0000	0	0	0	0,0047	0	0	0	0,0000	0,0000	0,0047	0,0515	0,0000	0,0000	0,0000	0,0200	0,0000	0,0000	0,0000	0,0000	0,000
Trigo em grão e outros cer	P_{16}	0,0000	0	0	0	0,0002	0	0	0	0,0000	0,0000	0,0002	0,0000	0,0000	0,0000	0,0000	0,0070	0,0000	0,0000	0,0000	0,0000	0,000
Soja em grão	P_{17}	0,0000	0	0	0	0,0116	0	0	0	0,0000	0,0000	0,0116	0,0007	0,0000	0,0000	0,0000	0,0573	0,0000	0,0000	0,0000	0,0000	0,000
Outros produtos e serviço	P_{18}	0,0000	0	0	0	0,0120	0	0	0	0,0000	0,0000	0,0120	0,0050	0,0000	0,0000	0,0000	0,0089	0,0000	0,0055	0,0000	0,0000	0,000
Mandioca	P_{19}	0,0000	0	0	0	0,0131	0	0	0	0,0000	0,0000	0,0131	0,0031	0,0000	0,0000	0,0000	0,0051	0,0000	0,0000	0,0000	0,0000	0,000
Fumo em folha	P_{20}	0,0000	0	0	0	0,0005	0	0	0	0,0000	0,0000	0,0005	0,0000	0,0000	0,0000	0,0000	0,0000	0,4066	0,0000	0,0000	0,0000	0,000
Algodão herbáceo	P_{21}	0,0000	0	0	0	0,0003	0	0	0	0,0000	0,0000	0,0003	0,0001	0,0000	0,0000	0,0000	0,0058	0,0000	0,0643	0,0000	0,0000	0,000
Frutas cítricas	P_{22}	0,0000	0	0	0	0,0003	0	0	0	0,0000	0,0000	0,0003	0,0002	0,0000	0,0000	0,0000	0,0133	0,0000	0,0000	0,0000	0,0000	0,000
Café em grão	P_{23}	0,0000	0	0	0	0,0007	0	0	0	0,0000	0,0000	0,0007	0,0002	0,0000	0,0000	0,0000	0,0104	0,0000	0,0000	0,0000	0,0000	0,000
Produtos da exploração fl	P_{24}	0,0000	0	0	0	0,0101	0	0	0	0,0000	0,0000	0,0101	0,0034	0,0000	0,0000	0,0000	0,0019	0,0000	0,0005	0,0000	0,0007	0,112
Bovinos e outros animais	P_{25}	0,0000	0	0	0	0,0005	0	0	0	0,0000	0,0000	0,0005	0,0102	0,0000	0,0000	0,0000	0,0703	0,0000	0,0028	0,0000	0,0000	0,000
Leite de vaca e de outros a	P_{26}	0,0000	0	0	0	0,0000	0	0	0	0,0000	0,0000	0,0000	0,0032	0,0000	0,0000	0,0000	0,0424	0,0000	0,0000	0,0000	0,0000	0,000
Suínos vivos	P_{27}	0,0000	0	0	0	0,0000	0	0	0	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0157	0,0000	0,0000	0,0000	0,0000	0,000
Aves vivas	P_{28}	0,0000	0	0	0	0,0000	0	0	0	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0420	0,0000	0,0000	0,0000	0,0000	0,000
Ovos de galinha e de outra	P_{29}	0,0000	0	0	0	0,0001	0	0	0	0,0000	0,0000	0,0001	0,0285	0,0000	0,0000	0,0000	0,0025	0,0000	0,0000	0,0000	0,0000	0,000
Pesca e aquicultura	P_{30}	0,0000	0	0	0	0,0000	0	0	0	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0027	0,0000	0,0000	0,0000	0,0000	0,000
Petróleo e gás natural	P_{31}	0,0000	0	0	0	0,0000	0	0	0	0,0239	0,0239	0,0000	0,0000	0,0322	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,000
Minério de ferro	P_{32}	0,0000	0	0	0	0,0000	0	0	0	0,0000	0,0000	0,0000	0,0000	0,0000	0,0720	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,000
Carvão mineral	P_{33}	0,0000	0	0	0	0,0000	0	0	0	0,0003	0,0003	0,0000	0,0000	0,0000	0,0022	0,0014	0,0000	0,0000	0,0000	0,0000	0,0000	0,000
Minerais metálicos não-fe	P_{34}	0,0000	0	0	0	0,0000	0	0	0	0,0000	0,0000	0,0000	0,0000	0,0000	0,0023	0,0072	0,0000	0,0000	0,0000	0,0000	0,0000	0,000
Minerais não-metálicos	P_{35}	0,0002	0	0	0	0,0003	0,0054	0,0054	0,0055	0,0000	0,0000	0,0003	0,0105	0,0000	0,0033	0,0505	0,0002	0,0000	0,0000	0,0000	0,0003	0,000
Abate e preparação de pro	P_{36}	0,0000	0	0	0	0,0000	0	0	0	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0086	0,0000	0,0000	0,0005	0,0633	0,000
Carne de suíno fresca, refr	P_{37}	0,0000	0	0	0	0,0000	0	0	0	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0082	0,0000	0,0000	0,0000	0,0000	0,000
Carne de aves fresca, refri	P_{38}	0,0000	0	0	0	0,0000	0	0	0	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0058	0,0000	0,0000	0,0000	0,0000	0,000
Pescado industrializado	P_{39}	0,0000	0	0	0	0,0000	0	0	0	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0007	0,0000	0,0000	0,0000	0,0000	0,000

Shock final demand

2

R$ 1,000,000 Ethanol final demand (Y)

3

		Setores de compra						Demanda final	Valor produção
								Y	X
		1	2	...	j	...	73		
Produtos vendidos	1	z_{11}	z_{12}		z_{1j}		$z_{1\text{-}73}$		
	2	z_{21}	z_{22}		z_{2j}		$z_{2\text{-}73}$		
	...	...	...		...		...		
	i	z_{i1}	z_{i2}		z_{ij}		$z_{i\text{-}73}$		
	...	...	...		...		...		
	120	z_{n1}	z_{n2}		z_{nj}		$z_{120\text{-}73}$		
Valor adicionado	W								
Despesas totais	X^t								

Impact on sector outputs (X)

Economic Impact

Top 5 Direct and indirect inputs

Biorefinery outputs

Scenario 1G 2009	Impact (R$) 2050095
Ethanol (1G 2009)	1000000
Sugarcane (1G-2009)	477114
Inorganic chemicals	85020
Trade	58409
Diesel	50024
Petroleum and natural gas	39330
Other refined petroleum products and c	35225
Cargo transportation services	30847
Electricity, gas, water, sewage and urba	19369
Financial services and insurance	18948
Agricultural pesticides	18723
Services to companies	18144
Other non-metallic mineral products	17386
Electricity generation	15307
Pharmaceuticals	13834
Gasoline	13756
Sugar	12265
Non-metallic minerals	9895
Information services	9802
Repair and maintenance services	9720

Scenario 1G optimized	Impact (R$) 2423486
Ethanol (1G optmized)	1000000
Sugarcane (1G optimized)	506648
Electricity generation (1G optmized)	316068
Inorganic chemical products	84425
Diesel	62358
Trade	62054
Petroleum and gas	37173
Cargo transportation services	31857
Other non-metallic mineral products	21664
Electricity, gas, water, sewage and u	20548
Financial services and insurance	20517
Agricultural pesticides	19907
Services to companies	19047
Other refined petroleum products a	17665
Pharmaceuticals	17320
Other chemicals	16752
Electricity generation	15083
Gasoline	12961
Sugar	12086
Repair and maintenance services	11679

Economic Impact

Biorefinery outputs

Top 5 Direct and Indirect inputs

Scenario 1G optimized	Impact (R$) 2423486
Ethanol (1G optmized)	1000000
Sugarcane (1G optimized)	506648
Electricity generation (1G optmized)	316068
Inorganic chemical products	84425
Diesel	62358
Trade	62054
Petroleum and gas	37173
Cargo transportation services	31857
Other non-metallic mineral products	21664
Electricity, gas, water, sewage and u	20548
Financial services and insurance	20517
Agricultural pesticides	19907
Services to companies	19047
Other refined petroleum products a	17665
Pharmaceuticals	17320
Other chemicals	16752

Scenario 1G2G	Impact (R$) 1888559
Ethanol (1G2G)	1000000
Sugarcane (1G2G)	355749
Electricity generation (1G2G)	97646
Inorganic chemical products	55914
Diesel	45152
Trade	44990
Petroleum and natural gas	26241
Cargo transportation services	22781
Other chemicals	19738
Electricity, gas, water, sewage and urba	15152
Other non-metallic mineral products	15039
Financial services and insurance	14779
Agricultural pesticides	14100
Services to companies	13858
Pharmaceuticals	12869
Other refined petroleum products and c	11291

Diesel, petroleum and natural gas are required to produce indirect inputs due to the Brazilian technological structure

Environmental impact

4

Environmental burden array (R)

		Setores de compra						Demanda final	Valor produção	Carga ambiental
								Y	X	
		1	*2*	...	*j*	...	*73*			
Produtos vendidos	*1*	z_{11}	z_{12}		z_{1j}		$z_{1\text{-}73}$			
	2	z_{21}	z_{22}		z_{2j}		$z_{2\text{-}73}$			
	...	...	...		...		...			
	i	z_{i1}	z_{i2}		z_{ij}		$z_{i\text{-}73}$			
	...	...	...		...		...			
	120	z_{n1}	z_{n2}		z_{nj}		$z_{120\text{-}73}$			
Valor adicionado	W									
Despesas totais	X^T									

Environmental impact

Environmental burden array (R)

Average on-site emission	(g CO2eq / R$)
Paddy rice	1341,78
Corn	418,45
Wheat and other cereal grains	277,28
Soybean	283,47
Other crop products	60,76
Cassava	334,71
Tobacco	158,64
Upland cotton	176,37
Citric fruits	192,34
Coffee bean	204,90
Forestry products	207,60

Data related to **on-site emissions** for 120 products (not only agricultural)

Environmental impact

Straw Burning, manual harvesting

Emissions already allocated to ethanol (economic criteria)

No burning, manual harvesting

Scenario 1G 2009

Input	Emission (g CO_{2eq}/L)
Overall	693,45
Sugarcane (1G-2009)	414,29
Diesel	123,71
Ethanol (1G 2009)	45,11
Gasoline	35,70
Inorganic chemicals	12,99
Other refined petroleum produ	10,11
Petroleum and natural gas	8,76
Fuel oil	7,00
Cement	6,97
Other non-metallic mineral pro	5,76
Electricity generation	4,86
Sugarcane	4,72
Organic chemicals	2,32
Electric power transmission	2,22
Electricity, gas, water, sewage	2,12
Coal	0,97
Cargo transportation services	0,92
Resins and elastomers	0,72
Cattle and other livestock	0,61
Agricultural pesticides	0,43

Scenario 1G optimized

Input	Emission (g CO_{2eq}/L)
Overall	331,81
Diesel	117,20
Sugarcane (1G-optimized)	82,53
Etanol (1G-optimized)	47,13
Gasoline	25,56
Inorganic chemicals	9,80
Petroleum and natural gas	6,29
Cement	6,14
Fuel oil	5,64
Other non-metallic mineral	5,46
Other refined petroleum pr	3,85
Electricity generation	3,64
Electricity generation (1G-	3,58
Sugarcane	3,53
Organic chemicals	2,06
Electric power transmissio	1,73
Electricity, gas, water, sew	1,71
Resins and elastomers	0,78
Coal	0,77
Cargo transportation servi	0,72
Cattle and other livestock	0,50

Environmental impact

Yield: 64.7 kg ethanol/TC

Yield: 92 kg ethanol/TC

Scenario 1G optimized

Input	Emission (g CO_{2eq}/L)
Overall	331.81
Diesel	117,20
Sugarcane (1G-optimized)	82,53
Etanol (1G-optimized)	47,13
Gasoline	25,56
Inorganic chemicals	9,80
Petroleum and natural gas	6,29
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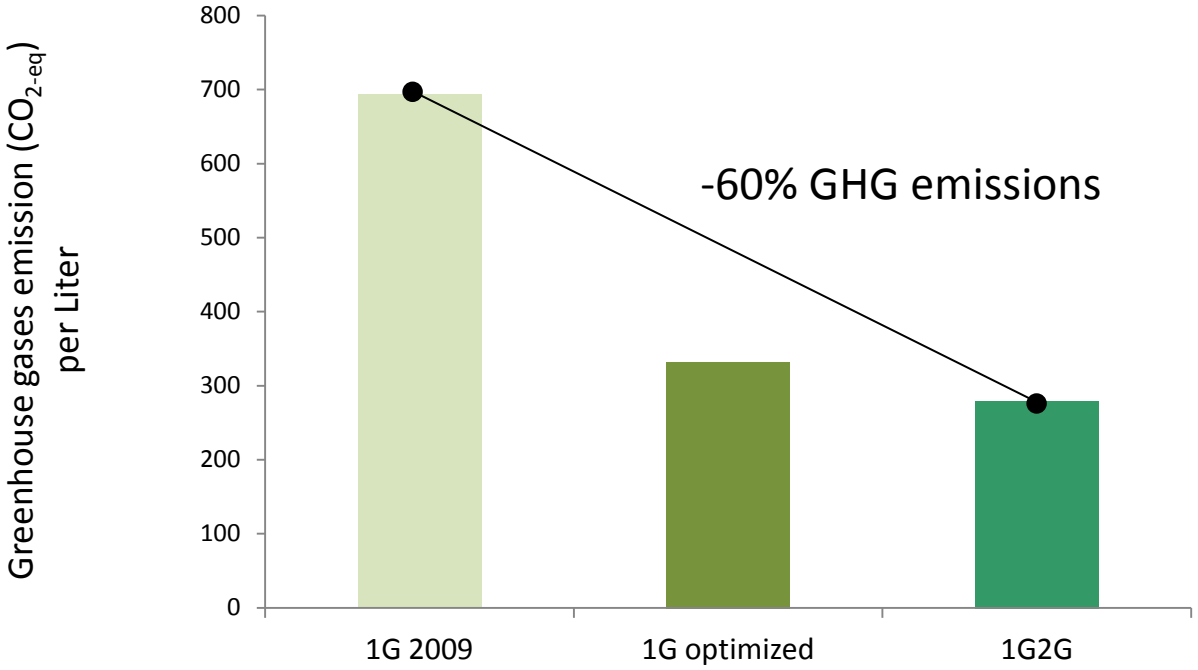
Fuel oil	5,64
Other non-metallic mineral	5,46
Other refined petroleum pr	3,85
Electricity generation	3,64
Electricity generation (1G-(	3,58
Sugarcane	3,53
Organic chemicals	2,06
Electric power transmissio	1,73
Electricity, gas, water, sew	1,71
Resins and elastomers	0,78

Scenario 1G2G

Input	Emission (g CO_{2eq}/L)
Overall	279,15
Diesel	101,62
Sugarcane (1G2G)	76,27
Ethanol (1G2G)	32,29
Gasoline	21,59
Inorganic chemicals	7,77
Petroleum and natural gas	5,32
Cement	5,30
Fuel oil	4,76
Other non-metallic mineral pro(	4,54
Electricity generation	3,08
Sugarcane	2,99
Other refined petroleum produ(	2,95
Organic chemicals	1,94
Electricity, gas, water, sewage	1,51
Electric power transmission	1,45
Resins and elastomers	0,83
Coal	0,66

Environmental impact

- 1G 2009 : average emission 693 $gCO_{2\ eq}/L$
- 1G2G : average emission 280 $gCO_{2\ eq}/L$
- **Potential reduction:** 410 g CO_{2eq}/L



Future challenges

- **Sensitivity analysis :** uncertainty related to prices?

- **Disaggregate** direct and indirect impacts

$$X = [I + A]Y \quad + \quad X = [A^2 + A^3 + \ldots + A^n]Y$$

- **Structural Path Analysis (PAT):** track emissions considering tier 0 (direct suppliers), tier 1, tier 2, tier 3 (indirect suppliers), and so on.

- **Increase the amount of** environmental burden arrays

- **Results: comparison with** process-based LCA

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Thanks !

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